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INTERACTIONAL AERODYNAMICS OF THE SINGLE ROTOR HELICOPTER CONFIDENTIAL (U)

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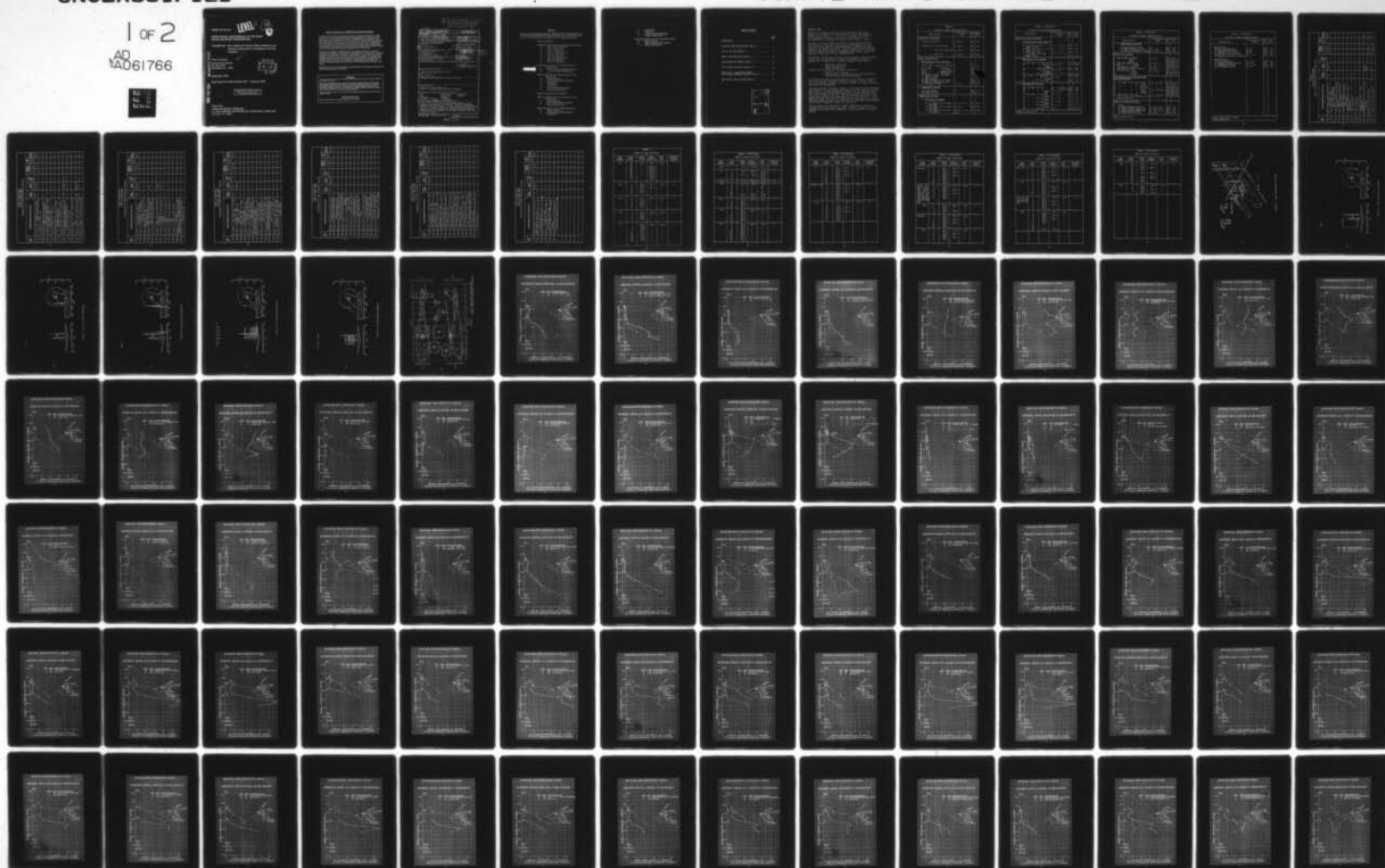
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LEVEL III



USARTL-TR-78-23C

**INTERACTIONAL AERODYNAMICS OF THE SINGLE
ROTOR HELICOPTER CONFIGURATION**

**VOLUME IIIA - Flow Angle and Velocity Wake Profiles in Low
Frequency Band, Basic Investigations and Hub
Variations**

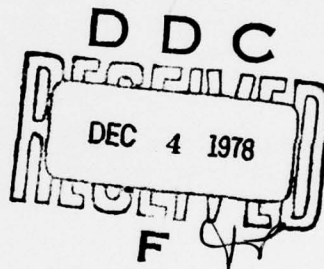
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Prepared for

APPLIED TECHNOLOGY LABORATORY

U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

In 1975 a wind tunnel test program was conducted in the Boeing-Vertol 20-foot V/STOL Wind Tunnel on a 1/5th-scale UTTAS model to investigate and find solutions for several aerodynamic problems encountered during the UTTAS flight-testing. Specifically, these tests focused upon (a) the structure of the hub/rotor wake in the vicinity of the empennage, (b) the formulation of the ground vortex and its relation to hub loads and fuselage loads during transition, and (c) the occurrence of vibratory air pressures from the blade passing over the fuselage. Only portions of the above-mentioned wind tunnel test data were reduced and analyzed in addressing the flight-test problems of the UTTAS aircraft.

Under Contract DAAJ02-77-C-0020, Boeing-Vertol completed analyses on the data to understand more completely the aerodynamic interactions that are involved and to formulate instructions for the guidance of designers in these respects. The results of these studies are applicable to all existing and future single-rotor/tail rotor helicopters. The data have been segregated according to aerodynamic interactions and associated phenomena/problem areas. From this body of knowledge, a generalized set of design guidelines meaningful to the single-rotor helicopter design concept formulation were developed and are included in these reports.

Mr. Robert P. Smith of the Aeronautical Technology Division, Aeromechanics Technical Area, served as project engineer for this effort.

DISCLAIMERS

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This is the first of the two sub-volumes comprising Volume III. These documents present profiles of the RMS values of the wake flow angles and velocities in the 1Ω to 2Ω range. The format is waterline on the ordinate and velocity or flow angle on the abscissa. Each graph shows a comparison of the baseline flow to the flow modified by some device or condition. This sub-volume covers build-up to baseline, baseline wake exploration and the effects of various hub caps.			

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PREFACE

The entire report describing the investigation of INTERACTIONAL AERODYNAMICS OF THE SINGLE-ROTOR HELICOPTER CONFIGURATION comprises eight numbered volumes bound as 33 separate documents. The complete list of these documents is as follows:

Volume I, Final Report

Volume II, Harmonic Analyses of Airframe Surface Pressure Data

- A — Runs 7-14, Forward Section
- B — Runs 7-14, Mid Section
- C — Runs 7-14, Aft Section
- D — Runs 15-22, Forward Section
- E — Runs 15-22, Mid Section
- F — Runs 15-22, Aft Section
- G — Runs 23-33, Forward Section
- H — Runs 23-33, Mid Section
- I — Runs 23-33, Aft Section

Volume III, Flow Angle and Velocity Wake Profiles in Low-Frequency Band

This volume is

- A — Basic Investigations and Hubcap Variations
- B — Air Ejector Systems and Other Devices

Volume IV, One-Third Octave Band Spectrograms of Wake Split-Film Data

- A — Buildup to Baseline
- B — Basic Configuration Wake Explorations
- C — Solid Hubcaps
- D — Open Hubcaps
- E — Air Ejectors
- F — Air Ejectors With Hubcaps; Wings
- G — Fairings and Surface Devices

Volume V, Harmonic Analyses of Hub Wake

Volume VI, One-Third Octave Band Spectrograms of Wake Single Film Data

- A — Buildup to Baseline
- B — Basic Configuration Wake Exploration
- C — Hubcaps and Air Ejectors

Volume VII, Frequency Analyses of Wake Split-Film Data

- A — Buildup to Baseline
- B — Basic Configuration Wake Explorations
- C — Solid Hubcaps

- D - Open Hubcaps
- E - Air Ejectors
- F - Air Ejectors With Hubcaps; Wings
- G - Fairings and Surface Devices

Volume VIII, Frequency Analyses of Wake Single Film Data

- A - Buildup to Baseline
- B - Basic Configuration Wake Exploration
- C - Hubcaps and Air Ejectors

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INTRODUCTION

Volume III presents profiles of the wake split film data appearing in Volume IV in the one-third octave band format. Specifically, bands 7, 8, 9 and 10 in the plots of Volume IV are averaged to produce a mean value typifying the 1Ω to 2Ω regime where structural frequencies are likely to occur.

Volume III presents graphs of these 1Ω to 2Ω mean values for the four wake parameters plotted versus measurement location. The profile for each run (configuration) is compared in this format to the baseline profile. The difference in the profiles displays the effectivity of the model configuration in reducing the flow angles and velocity components and, hence, gauges the success of each step in the investigations.

The graphs showing these profiles are arranged in the same order as the runs in the Outline of Wake Investigations (Table 1). Volume III-A includes the following categories from Table 1:

- Build-up to Baseline
- Basic Configuration
- Effect of Hub Caps

Volume III-B includes the following categories:

- Effect of Air Ejectors
- Air Ejectors with Open Hub Caps and Underbodies
- Effect of Wings and Miscellaneous

The Table I outline and other material is included for reference and as context to the work of each sub-volume. Table 2, the List of Test Runs, arranges the runs in numerical order and gives pertinent text parameters.

The Index of Rake Positions, Table 3, lists the hot film transducer rake positions in the model coordinate system for each run and its test points. The main feature of Table 3 is the indexing of the test point number to the model water line station and butt line as it varied from run to run. The table groups the runs as they shared the indexing correspondence of point with position. It is emphasized that the runs in a group do not necessarily all share the same number of test points but they do have same correspondence within their respective ranges of test points.

The orientation of the rake is shown pictorially in Figures 1 through 6 for the various test runs. Figure 7 presents a scaled drawing of the model with reference to the three-axis coordinate system.

TABLE 1			
OUTLINE OF WAKE INVESTIGATIONS			
Description	Configuration Code	Run No.	Base-line
<u>Build-up to Baseline</u>			
1. Nacelles removed	$K_{13}+H_1-N$	149	150
2. Blades off, rotating hub	$K_{13}-M+H_{1.0}$	160	156
3. " " , non-rotating hub	$K_{13}-M+H_{1.0}$	158	156
4. " " , hub off	$K_{13}-M-H_{1.0}$	159	156
<u>Basic Configuration</u>			
<u>1. Wake Explorations near Empennage</u>			
(a) 15" Long. + traverse at T/R C.L.	K_{11}	111	---
(b) 9" Vert. + " above T/R "	"	112	---
(c) 2" " " in vortex	"	113	---
(d) 8" " " (continue 112)	"	114	---
(e) 13" " " behind stab.	"	115	---
(f) Lateral traverse, left stab. (One T.P. only)	"	116	---
(g) Same continued	"	117	---
(h) Same continued (One T.P. only)	"	118	---
(i) Lateral traverse right stab.	"	119	---
(j) T/R effect on wake	$K_{11}+T_2^0$	121	115
<u>2. Climb/Descent Studies</u>			
(a) Climb 900 FPM	K_{11}	135	---
(b) Descent 800 FPM	"	136	---
<u>Effect Of Hub Caps</u>			
<u>1. Solid Caps on Canister</u>			
(a) 7.6" diam. 2.17" ht. soft Pitch Arms	$K_{11}-H_{1.0}+H_{1.2}$	137	136
(b) 7.6" diam. 2.17" ht. stiff Pitch Arms	$K_{13}+H_{1.2}$	153	156
(b) 7.6" diam. 2.45" ht. flt. test config.	$K_{13}+H_{1.2.1}+I_1+E_{1.0}$	207	188

TABLE 1 (CONTINUED)

OUTLINE OF WAKE INVESTIGATIONS

Description	Configuration Code*	Run No.	Base-line
<u>Effect of Hub Caps (Continued)</u>			
2. <u>Solid Caps Raised Above Canister</u>			
(a) 7.6" diam. 2.45" ht. 70" depth, .55 gap	H _{1.2.2} +I ₁ +E _{1.0}	208	188
(b) 10.0" diam. 3.25" ht. 1.55" depth, .50" gap	H _{1.8.1} +I ₁ +E _{1.0}	189	188
(c) 10.0" diam. 4.125" ht. 2.05" depth, .875" gap	H _{1.8.2} +I ₁ +E _{1.0}	190	188
(d) Repeat of 189	" " "	210	188
3. <u>Open Caps Without Underbody</u>			
(a) 10.0" diam. 1.25" gap, blades	H _{1.0.2} +I ₁ +E _{1.0}	193	188/166
(b) " " " gap, no blades	H _{1.0.1} -M	166	158
(c) " " 2.05" gap, blades	H _{1.14.1} +I ₁ +E _{1.0}	211	188
(d) " " 1.75" gap, no blades	H _{1.0.1} -M	165	158
(e) " " 1.87" gap, blades	H _{1.0.3} +I ₁ +E _{1.0}	191	188
(f) 16" diam. 2.00" gap, blades	H _{1.7.1}	168	156/167
(g) " " " gap, no blades	H _{1.7.1} -M	167	158
(h) " " 4.00" gap, blades	H _{1.7.2}	169	156
4. <u>Open Caps with Underbody</u>			
(a) 7.6" diam. 1.25" gap	H _{1.11.1} +I ₂ +E _{1.0}	194	188
(b) " " " "	H _{1.11.1} +I ₂ +E _{4.0}	198	188
(c) " " " " center post	H _{1.11.2} +I ₂	202	194
(d) 10.0" diam. .5" gap, no blades	H _{1.5.1} -M	164	158
(e) " " 1.25" gap, no blades	H _{1.5.2} -M	161	158
(f) " " 2.0" gap, no blades	H _{1.5.4} -M	163	158
(g) " " 4.0" gap, no blades	H _{1.5.3} -M	162	158
(h) " " 1.25" gap	H _{1.5.2}	154	156/161
*Basic Code is K13.			

TABLE 1 (CONTINUED)

OUTLINE OF WAKE INVESTIGATIONS

Description	Configuration Code*	Run No.	Base-line
<u>5. Miscellaneous Hub Covers</u>			
(a) Hub fairing 16" diam.	H _{1.3}	151	150
(b) Wham-O-Frisbee 10" diam.	H _{1.9.0} +E _{1.2}	182	181
(c) Fab. glass Frisbee 16" diam.	H _{1.9.1} +E _{1.2}	183	181
<u>Effect of Air Ejectors</u>			
1. Basic system no blowing	H _{1.0} +E _{1.0}	172	156
2. " " 40 psi	" "	173	156/172
3. " " 150 psi	" "	174	156/172
4. Wide chord shroud 40 psi	H _{1.0} +E _{2.5.1}	175	156/173
5. Wide " " 150 psi	" "	176	156/174
6. W/C shroud w. lip 40 psi	H _{1.0} +E _{3.5.2}	184	156/173
7. Same Contoured Parallel 150 psi	H _{1.0} +E _{3.5.4}	187	156/174
8. Bifurcated duct 0 psi	H _{1.0} +E _{5.0}	203	156
9. " " 40 psi	" "	204	156/203
10. " " 150 psi	" "	205	156/203
<u>Air Ejectors with Open Hub Caps with Underbodies</u>			
1. 7.6" diam. 1.25" gap, 0 psi	H _{1.11.1} +I ₂ +E _{1.0}	194	188/172
2. " " " " 20 psi	" " "	195	188
3. " " " " 40 psi	" " "	196	188/173
4. " " " " 150 psi	" " "	197	188/174
5. " " " " 0 psi	H _{1.11.1} +I ₂ +E _{4.0}	198	188/194
6. " " " " 40 psi	" " "	199	188/196
7. " " " " 150 psi	" " "	200	188/196
8. Same with center post	H _{1.11.2} +I ₂ +E _{4.6}	201	188/200
9. 10.0" diam. 2.0" gap wide ch'd shroud (150 psi)	H _{1.5.4} +E _{2.5.1}	177	156/176
<u>Effect of Wings and Misc.</u>			
1. Wings			
(a) Nacelle-mounted stub wing	H _{1.0} +W _{1.0} +E _{1.1}	178	181
(b) Single slotted flapped wing	H _{1.0} +W _{3.0} +E _{1.0}	180	181
(c) Double slotted flapped wing	H _{1.0} +W _{2.0} +E _{1.0}	179	181
(d) Boom-mounted stub wing	H _{1.0} +W _{4.0}	186	156
*Basic Code is K13.			

TABLE 1 (CONTINUED)

OUTLINE OF WAKE INVESTIGATIONS

Description	Configuration Code*	Run No.	Base-line
2. Crown Fairings			
(a) Flat top behind shaft	K ₁₁ +D ₁	140	138
(b) Round top behind shaft	K ₁₁ +D ₂	141	138
(c) Extended flat top fairing	H ₁ +D ₄	170	156
(d) Flat top + 16" cap, 4" gap	H _{1.7.2} +D ₄	171	170
(e) Forward fairing/nacelle fairing	P _{1.0}	152	156
3. Surface Devices			
(a) Vortex generators	K ₁₁ +VG _{2.1}	139	138
(b) Guidevane between nacelles	K ₁₁ +FV ₁	142	138
(c) Longitudinal strakes	H _{1.5.3} +S ₄	155	156
(d) 14% porosity spoiler	K ₁₁ +X ₁	143	138
*Basic Code is K13 unless noted otherwise.			

TABLE 2
LIST OF TEST RUNS
BASIC INVESTIGATIONS OF THE HUB WAKE

RUN NO.	CONFIGURATION/CONDITION	V _{TUN} KNOTS	RPM MR/TR	DISK LDG. psf	MODEL ANGLES		MR HT. h/d	TAIL ROTOR
					α°	ψ°		
111	K ₁₁ /15" Long. wake traverse at TR center line	80	1433/0	8	6.0	-2.0	∞	Off
112	" /9" Vert. wake traverse above TR center line	"	"	"	"	"	"	"
113	" /2" Vert traverse through MR vortex	"	"	"	"	"	"	"
114	" /8" Vert. traverse below TR center line	"	"	"	"	"	"	"
115	" /13" Vert. traverse behind stabilizer	"	"	"	"	"	"	"
116	" /Lateral traverse - left stabilizer	"	"	"	"	"	"	"
117	" /116 continued	"	"	"	"	"	"	"
118	" /116 continued	"	"	"	"	"	"	"
119	" /Lateral traverse - right stabilizer	"	"	"	"	"	"	"
121	K ₁₁ +T ₂ /Effect of tail rotor flow on wake	"	1433/4500	"	"	"	"	On
135	K ₁₁ /Wake in 900 fpm climb	"	"	"	-6.0	-4.5	"	Off
136	" /Wake in 800 fpm descent	"	"	"	6.0	+2.0	"	"

TABLE 2 (CONTINUED)
LIST OF TEST RUNS
EVALUATION OF WAKE-ALTERING DEVICES

RUN NO.	CONFIGURATION/CONDITION	VTUN KNOTS	RPM MR/TR	DISK LDG. psf	MODEL ANGLES		MR HT.	TAIL ROTOR
					α°	ψ°		
137	K ₁₁ -H _{1.0} +H _{1.2} /Effect of 7.6 inch diam. solid hub cap	80	1433/0	8	6	-3.8	∞	Off
138	K ₁₁ /Repeat of base run	"	"	"	"	"	"	"
139	K ₁₁ +VG _{2.1} /Effect of vortex generators on aft crown	"	"	"	"	"	"	"
140	K ₁₁ +D ₁ /Flat-topped "doghouse" fairing on aft crown	"	"	"	"	"	"	"
141	K ₁₁ +D ₂ /Rounded-top fairing	"	"	"	"	"	"	"
142	K ₁₁ +FV ₁ /Deflection vane on crown between nacelles	"	"	"	"	"	"	"
143	K ₁₁ +X ₁ /Variable porosity spoiler	"	"	"	"	"	"	"
149	K ₁₃ +H ₁ -N ₁ /Effect of nacelles off also add stiff pitch arms (K ₁₃)	60	1075/0	4.5	"	"	"	"
150	K ₁₃ +H ₁ /60 knot baseline	"	"	"	"	"	"	"
151	K ₁₃ +H _{1.3} /16 inch diam. helmet fairing	"	"	"	"	"	"	"
152	K ₁₃ +P _{1.0} /Pylon and intake fairings	80	1433/0	8	"	"	"	"
153	K ₁₃ +H _{1.2} /Repeat 137 with K ₁₃ pitch arms	"	"	"	"	"	"	"

TABLE 2 (CONTINUED)
LIST OF TEST RUNS
EVALUATION OF WAKE-ALTERING DEVICES

RUN NO.	CONFIGURATION/CONDITION	VTUN KNOTS	RPM MR/TR	DISK LDG. psf	MODEL ANGLES		MR HT. h/d	TAIL ROTOR
					α°	ψ°		
154	K ₁₃ +H _{1.5.2/10} " open hub cap, 7" underbody, 1.25" gap	80	1433/0	8	6	-3.8	∞	Off
155	K ₁₃ +H _{1.5.2} +S ₄ /Same as 154 except strakes on aft crown	"	"	"	"	"	"	"
156	K ₁₃ +H _{1.0} /Baseline with K ₁₃ , i.e., stiff pitch arms	"	"	"	"	"	"	"
158	K ₁₃ -M+H _{1.0} /Wake studies with blades off, hub not rotating	"	0/0	"	"	"	"	"
159	K ₁₃ -M-H _{1.0} /Wake studies with hub off	"	"	"	"	"	"	"
160	K ₁₃ -M+H _{1.0} /Same as 158 except hub is rotating	"	1433/0	"	"	"	"	"
161	K ₁₃ -M+H _{1.5.2} /Repeat of 154 without blades	"	0/0	"	"	"	"	"
162	K ₁₃ -M+H _{1.5.3} /Same as 161 except 4" gap	"	"	"	"	"	"	"
163	K ₁₃ -M+H _{1.5.4} /Same as 161 except 2" gap	"	"	"	"	"	"	"
164	K ₁₃ -M+H _{1.5.1} /Same as 161 except 0.5" gap	"	"	"	"	"	"	"
165	K ₁₃ -M+H _{1.0.1/10} " open hub cap, no underbody, same cap vert. position as Run 154	"	"	"	"	"	"	"
166	K ₁₃ -M+H _{1.0.2} /Same as 165 with cap lowered by 0.5"	"	"	"	"	"	"	"

TABLE 2 (CONTINUED)
LIST OF TEST RUNS
EVALUATION OF WAKE-ALTERING DEVICES

RUN NO.	CONFIGURATION/CONDITION	VTUN KNOTS	RPM MR/TR	DISK LDG. psf	MODEL ANGLES		MR HT. h/d	TAIL ROTOR
					α°	ψ°		
167	K ₁₃ -M+H _{1.7.1} /16" open cap, no underbody, 2" gap	80	0/0	8	6	-3.8	∞	Off
168	K ₁₃ +H _{1.7.1} /Blades on, same cap config. as 167	"	1433/0	"	"	"	"	"
169	K ₁₃ +H _{1.7.2} /16" open cap, no underbody, 4" gap	"	"	"	"	"	"	"
170	K ₁₃ +H _{1.0} +D _{4.0} /Extended flat top fairing on aft crown	"	"	"	"	"	"	"
171	K ₁₃ +H _{1.7.2} +D _{4.0} /Same fairing as 170, same cap as 169	"	"	"	"	"	"	"
172	K ₁₃ +H _{1.0} +E _{1.0} (0psi)/Basic air ejector zero blowing baseline	"	"	"	"	"	"	"
173	K ₁₃ +H _{1.0} +E _{1.0} (40 psi)/Same as 172 with 40 psi supply	"	"	"	"	"	"	"
174	K ₁₃ +H _{1.0} +E _{1.0} (150 psi)/Same as 172 with 150 psi supply	"	"	"	"	"	"	"
175	K ₁₃ +H _{1.0} +E _{2.5.1} (40 psi)/Ejector with wide chord shroud at 40 psi	"	"	"	"	"	"	"
176	K ₁₃ +H _{1.0} +E _{2.5.1} (150 psi)/Same as 174 with 150 psi supply	"	"	"	"	"	"	"
177	K ₁₃ +H _{1.5.4} +E _{2.5.1} (150 psi)/Same as 176 with 10" cap like 163	"	"	"	"	"	"	"
178	K ₁₃ +H _{1.0} +W _{1.0} +E _{1.1} (0 psi)/Nacelle mounted wing	"	"	"	"	"	"	"

TABLE 2 (CONTINUED)

LIST OF TEST RUNS

EVALUATION OF WAKE-ALTERING DEVICES

RUN NO.	CONFIGURATION/CONDITION	VTUN KNOTS	RPM MR/TR	DISK LDG. psf	MODEL ANGLES		MR HT. h/d	TAIL ROTOR
					α°	ψ°		
179	K ₁₃ +H _{1.0} +W _{2.0} +E _{1.0} (0 psi)/Double slotted flapped wing	80	1433/0	8	6	-3.8	∞	Off
180	K ₁₃ +H _{1.0} +W _{3.0} +E _{1.0} (0 psi)/Single slotted flapped wing	"	"	"	"	"	"	"
181	K ₁₃ +H _{1.0} +E _{1.2} (0 psi)/Baseline with ejector tube moved aft	"	"	"	"	"	"	"
182	K ₁₃ +H _{1.9.0} +E _{1.2} (0 psi)/Standard 10" frisbee	"	"	"	"	"	"	"
183	K ₁₃ +H _{1.9.1} +E _{1.2} (0 psi)/16" fabricated frisbee	"	"	"	"	"	"	"
184	K ₁₃ +H _{1.0} +E _{3.5.2} (40 psi)/Wide chord with lip at 40 psi	"	"	"	"	"	"	"
185	K ₁₃ +H _{1.0} +E _{3.5.2} (150 psi)/Same as 184 with 150 psi air	"	"	"	"	"	"	"
186	K ₁₃ +H _{1.0} +W _{4.0} /Boom mounted stub wing	"	"	"	"	"	"	"
187	K ₁₃ +H _{1.0} +E _{3.5.4} (150 psi)/Like 185 with modified shroud	"	"	"	"	"	"	"
188	K ₁₃ +H _{1.0} +I ₁ +E _{1.0} (0 psi)/Baseline with I ₁ instr. ring	"	"	"	"	"	"	"
189	K ₁₃ +H _{1.8.1} +I ₁ +E _{1.0} (0 psi)/Solid cap, 10" diam. 3.25" height	"	"	"	"	"	"	"
190	K ₁₃ +H _{1.8.2} +I ₁ +E _{1.0} (0 psi)/Same as 190 except + 4.12" height	"	"	"	"	"	"	"

TABLE 2 (CONTINUED)
LIST OF TEST RUNS
EVALUATION OF WAKE-ALTERING DEVICES

RUN NO.	CONFIGURATION/CONDITION	V _{TUN} KNOTS	RPM MR/TR	DISK LDG. psf	MODEL ANGLES		MR HT. h/d	TAIL ROTOR
					α°	ψ°		
191	K ₁₃ +H _{1.0.2} +I ₁ +E _{1.0} (0 psi)/10" cap, no underbody, 1.87" gap	80	1433/0	8	6	-3.8	∞	Off
193	K ₁₃ +H _{1.0.2} +I ₁ +E _{1.0} (0 psi)/10" cap, no underbody, 1.25" gap	"	"	"	"	"	"	"
194	K ₁₃ +H _{1.11.1} +I ₂ +E _{1.0} (0 psi)/7.6" cap, underbody, 1.25" gap	"	"	"	"	"	"	"
195	K ₁₃ +H _{1.11.1} +I ₂ +E _{1.0} (20 psi)/Same as 194 with 20 psi air	"	"	"	"	"	"	"
196	K ₁₃ +H _{1.11.1} +I ₂ +E _{1.0} (40 psi)/Same as 194 with 40 psi air	"	"	"	"	"	"	"
197	K ₁₃ +H _{1.11.1} +I ₂ +E _{1.0} (150 psi)/Same as 194 with 150 psi air	"	"	"	"	"	"	"
198	K ₁₃ +H _{1.11.1} +I ₂ +E _{4.0} (0 psi)/Same as 194 except blowing tube 2" aft	"	"	"	"	"	"	"
199	K ₁₃ +H _{1.11.1} +I ₂ +E _{4.0} (40 psi)/Same as 198 with 40 psi air	"	"	"	"	"	"	"
200	K ₁₃ +H _{1.11.1} +I ₂ +E _{4.0} (150 psi)/Same as 198 with 150 psi air	"	"	"	"	"	"	"
201	K ₁₃ +H _{1.11.2} +I ₂ +E _{4.0} (150 psi)/Same as 200 except center support cap	"	"	"	"	"	"	"
202	K ₁₃ +H _{1.11.2} +I ₂ /Baseline with I ₂ and no blowing tube	"	"	"	"	"	"	"
203	K ₁₃ +H _{1.0} +E _{5.0} (0 psi)/Bifurcated air duct baseline	"	"	"	"	"	"	"

TABLE 2 (CONTINUED)
LIST OF TEST RUNS
EVALUATION OF WAKE-ALTERING DEVICES

RUN NO.	CONFIGURATION/CONDITION	VTUN KNOTS	RPM MR/TR	DISK LDG. psf	MODEL ANGLES		MR HT. h/d	TAIL ROTOR
					α°	ψ°		
204	K13+H1.0+E5.0 (150 psi)/Bifurcated duct with 150 psi air	80	1433/0	8	6	-3.8	∞	Off
205	K13+H1.0+E5.0 (40 psi)/Same as 204 with 40 psi air	"	"	"	"	"	"	"
207	K13+H1.2.1+I1+E1.0 (0 psi)/7.6" solid cap, no gap	"	"	"	"	"	"	"
208	K13+H1.2.2+I1+E1.0 (0 psi)/Same as 207 except 0.55" gap	"	"	"	"	"	"	"
210	K13+H1.15.1+I1+E1.0 (0 psi)/Repeat of 189	"	"	"	"	"	"	"
211	K13+H1.14.1+I1+E1.0 (0 psi)/Like 189 and 210 except cap is open	"	"	"	"	"	"	"

TABLE 3					
INDEX TO RAKE POSITIONS					
RUN NUMBER	TEST POINT	WATER LINE	MODEL STATION	BUTT LINE	LOCATION FIGURE
111	20	53.5	103.1	-7.25	1
	21	"	"	"	
	22	"	105.0	"	
	24	"	107.0	"	
	26	"	109.0	"	
	28	"	111.0	"	
	30	"	112.9	"	
	32	"	114.9	"	
	34	"	116.9	"	
	36	"	118.9	"	
112	2	48.9	107.3	-7.25	1
	4	50.8	"	"	
	6	52.7	103.3	"	
	8	54.5	"	"	
	10	56.2	"	"	
	12	57.2	"	"	
113	2	51.7	103.3	-3.25	1
	4	52.3	"	"	
	6	52.8	"	"	
	8	53.3	"	"	
	10	53.9	"	"	
	11	53.3	"	"	
114	2	44.5	103.0	-3.25	1
	4	46.4	"	"	
	6	48.2	"	"	
	8	50.0	"	"	
	10	51.9	"	"	
115	3	52.9	124.7	-3.25	1
	4	52.0	"	"	
	6	50.0	"	"	
	9	48.0	"	"	
	10	46.0	"	"	
	12	44.1	"	"	
	14	42.1	"	"	
	16	53.0	"	"	
	18	54.0	"	"	
	20	55.0	"	"	

TABLE 3 (CONTINUED)
INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER LINE	MODEL STATION	BUTT LINE	LOCATION FIGURE
116	7	36.9	100.5	-17.5	1
117	2 4 6 8 10	37.6 " 37.3 " "	100.5 " 99.6 " "	-16.0 -14.0 -12.0 -10.0 - 8.0	1
118	2	37.6	100.5	- 6.0	1
119	2 5 8 9 14 16 20 25	37.3 " " " " " 51.5 52.3	99.6 " " " " " 102.5 101.7	+ 6.0 8 10 " 14 16 17.5 -17.5	1
121	3 4 6 8 10	62.9 53.5 50.1 46.0 42.1	129.0 " " " "	+ 5.7 " " " "	2
135	2 4 6 8 10 12 14	56.9 54.5 52.5 50.5 48.5 46.5 44.5	106.3 " " " " " "	- 5.7 " " " " " "	3
136	2 4 6 8 10 12 14 17 18 19	56.5 54.5 52.5 50.6 48.5 46.5 44.5 37.1 39.0 41.0	104.0 " " " " " " " " "	- 8.0 " " " " " " " " "	4

TABLE 3 (CONTINUED)
INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER LINE	MODEL STATION	BUTT LINE	LOCATION FIGURE
137	3	38.7	98.4	- 8.0	5
	5	39.9	"	"	
	7	42.0	100.5	"	
	9	44.0	"	"	
	11	46.0	103.6	"	
	13	48.0	"	"	
	15	50.0	"	"	
	17	52.0	"	"	
	19	54.0	"	"	
138-41, 143	2	38.8	98.4	- 8.0	5
	3	40.0	"	"	
	4	42.0	100.5	"	
	5	44.0	"	"	
	6	46.0	103.6	"	
	7	48.0	"	"	
	8	50.0	"	"	
	9	52.0	"	"	
	10	54.0	"	"	
142	7	37.8	98.4	- 8.0	5
	8	"	"	"	
	9	40.2	"	"	
	10	42.0	100.5	"	
	11	44.0	"	"	
	12	46.0	103.6	"	
	13	48.0	"	"	
	14	50.0	"	"	
	15	52.0	"	"	
	16	54.0	"	"	
	17	56.8	"	"	

TABLE 3 (CONTINUED)
INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER LINE	MODEL STATION	BUTT LINE	LOCATION FIGURE
149-151	2	38.8	98.5	- 8.0	5
	3	40.0	"	"	
	4	42.0	100.6	"	
	5	44.0	"	"	
	6	46.0	103.5	"	
	7	48.0	"	"	
	8	50.0	"	"	
	9	52.0	"	"	
	10	54.0	"	"	
152-6, 158	2	42.9	97.9	0.0	6
161-4, 166	3	44.9	"	"	
167, 169-71	4	46.9	100.6	"	
175, 177-9	5	48.9	"	"	
180, 182, 184	6	50.9	104.6	"	
186-8, 190	7	52.9	"	"	
191, 193, 194	8	54.9	"	"	
196, 198, 201	9	56.9	"	"	
204, 207, 208					
211					
159	1	54.9	104.6	0.0	6
	2	52.9	"	"	
	3	50.7	"	"	
	4	48.6	100.6	"	
	5	46.7	"	"	
160, 203	5	42.9	97.9	0.0	6
	6	44.9	"	"	
	7	46.9	100.6	"	
	8	48.9	"	"	
	9	50.9	104.6	"	
	10	52.9	"	"	
	11	54.9	"	"	
165	3	44.9	97.9	0.0	6
	4	42.9	"	"	
	5	46.9	100.6	"	
	6	48.9	"	"	
	7	50.9	104.6	"	
	8	52.9	"	"	

TABLE 3 (CONTINUED)
INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER LINE	MODEL STATION	BUTT LINE	LOCATION FIGURE
168, 183	4	42.9	97.9	0.0	6
	5	44.9	"	"	
	6	46.9	100.6	"	
	7	48.9	"	"	
	8	50.9	104.6	"	
	9	52.9	"	"	
	10	54.9	"	"	
172	3	42.9	97.9	0.0	6
	4	44.9	"	"	
	6	44.9	"	"	
	7	46.9	100.6	"	
	8	48.9	"	"	
	9	50.9	104.6	"	
	10	52.9	"	"	
173, 174, 176 185, 195, 197 199, 200, 205 210	11	54.9	"	"	
	1	42.9	97.9	0.0	6
	2	44.9	"	"	
	3	46.9	100.6	"	
	4	48.9	"	"	
	5	50.9	104.6	"	
	6	52.9	"	"	
181	7	54.9	"	"	
	2	42.9	97.9	0.0	6
	3	44.9	"	"	
	4	46.9	100.6	"	
	5	48.9	"	"	
	6	50.9	104.6	"	
	7	52.9	"	"	
	9	54.9	"	"	
	10	"	"	"	
	11	"	"	"	
	12	"	"	"	
	13	42.9	97.9	"	

[illegible]

RUN 121

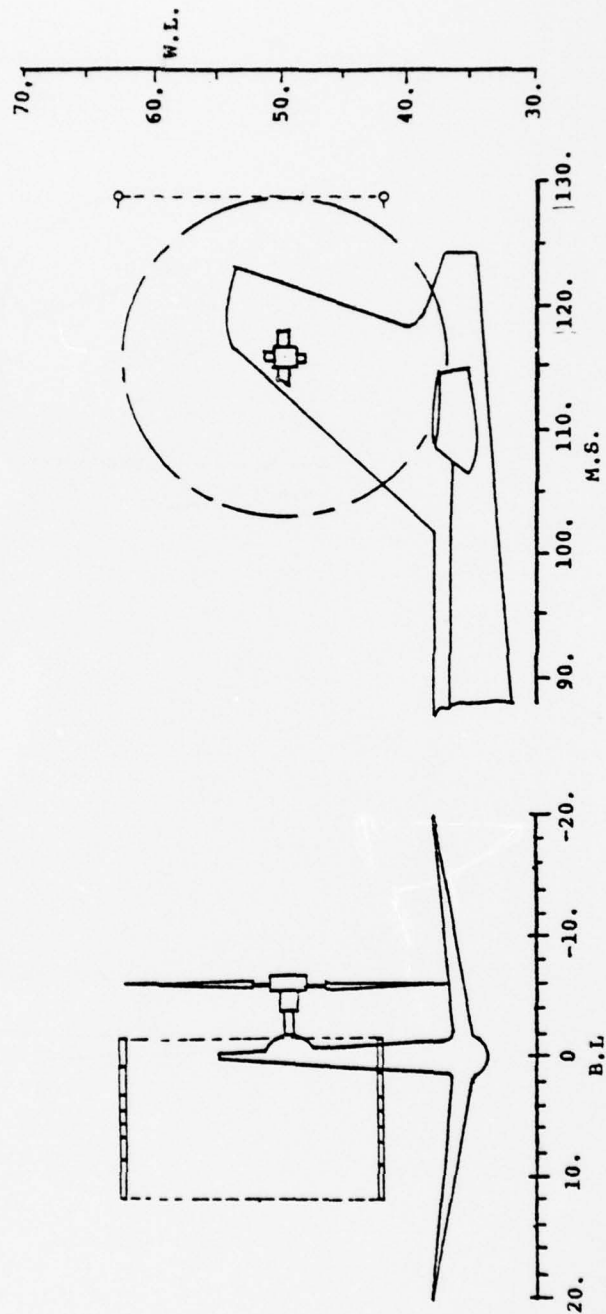


FIGURE 2 -HOT FILM RAKE LOCATIONS

RUN 135

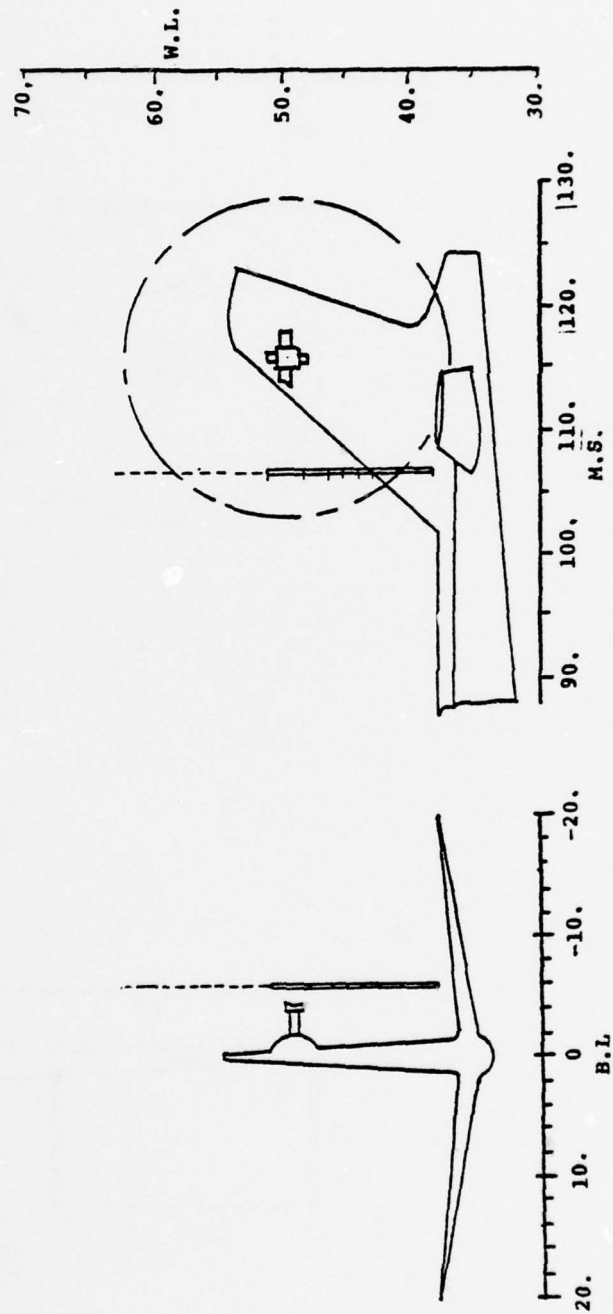


FIGURE 3 -HOT FILM RAKE LOCATIONS

RUN 136

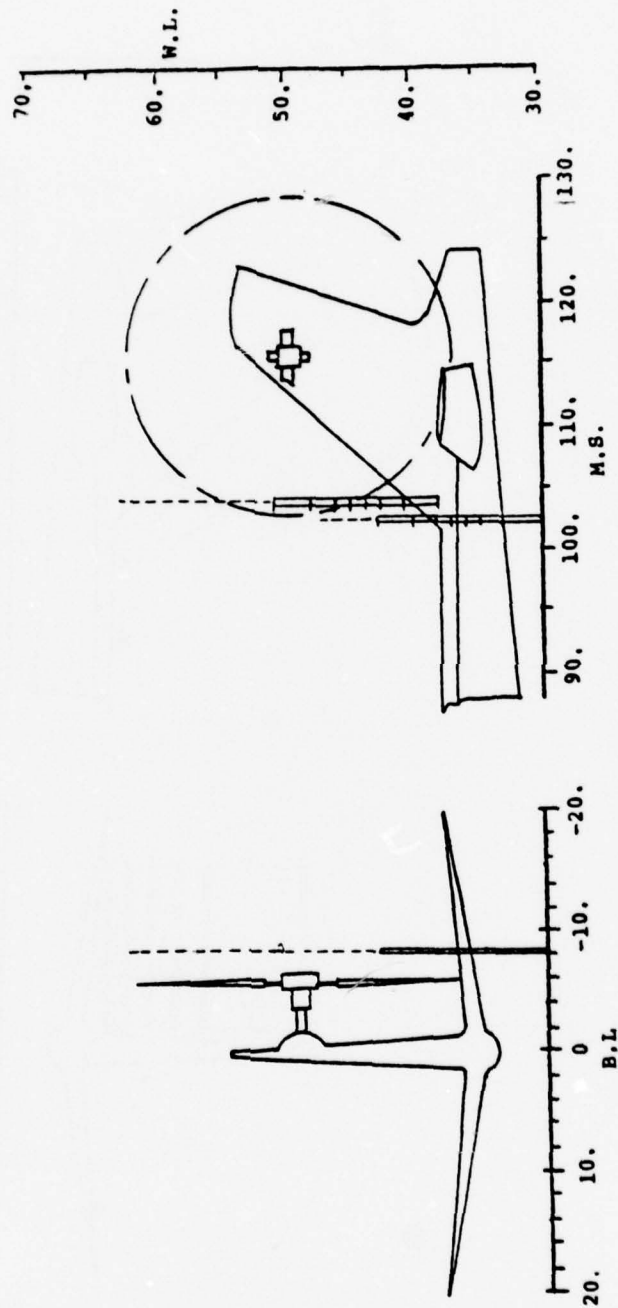


FIGURE 4 -HOT FILM RAKE LOCATIONS

RUN 137, 138, 139, 140, 141, 142,
143, 148, 149, 150, 151

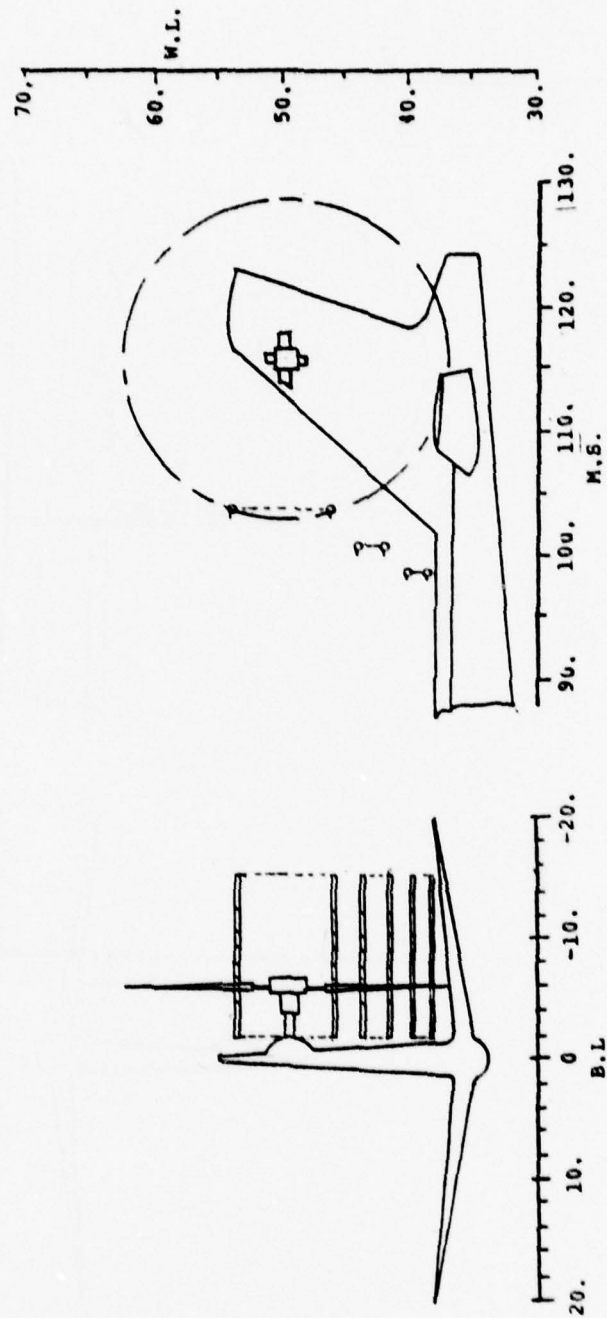


FIGURE 5 -HOT FILM RAKE LOCATIONS

RUN 152-156, 158-211

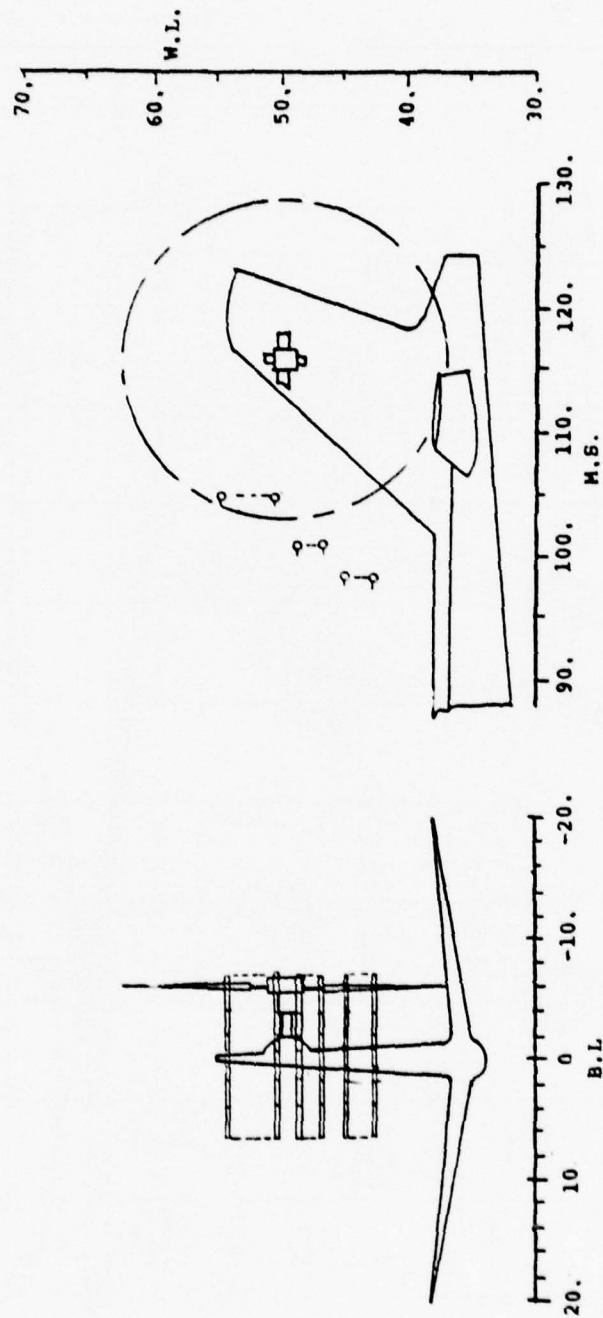


FIGURE 6 -HOT FILM RAKE LOCATIONS

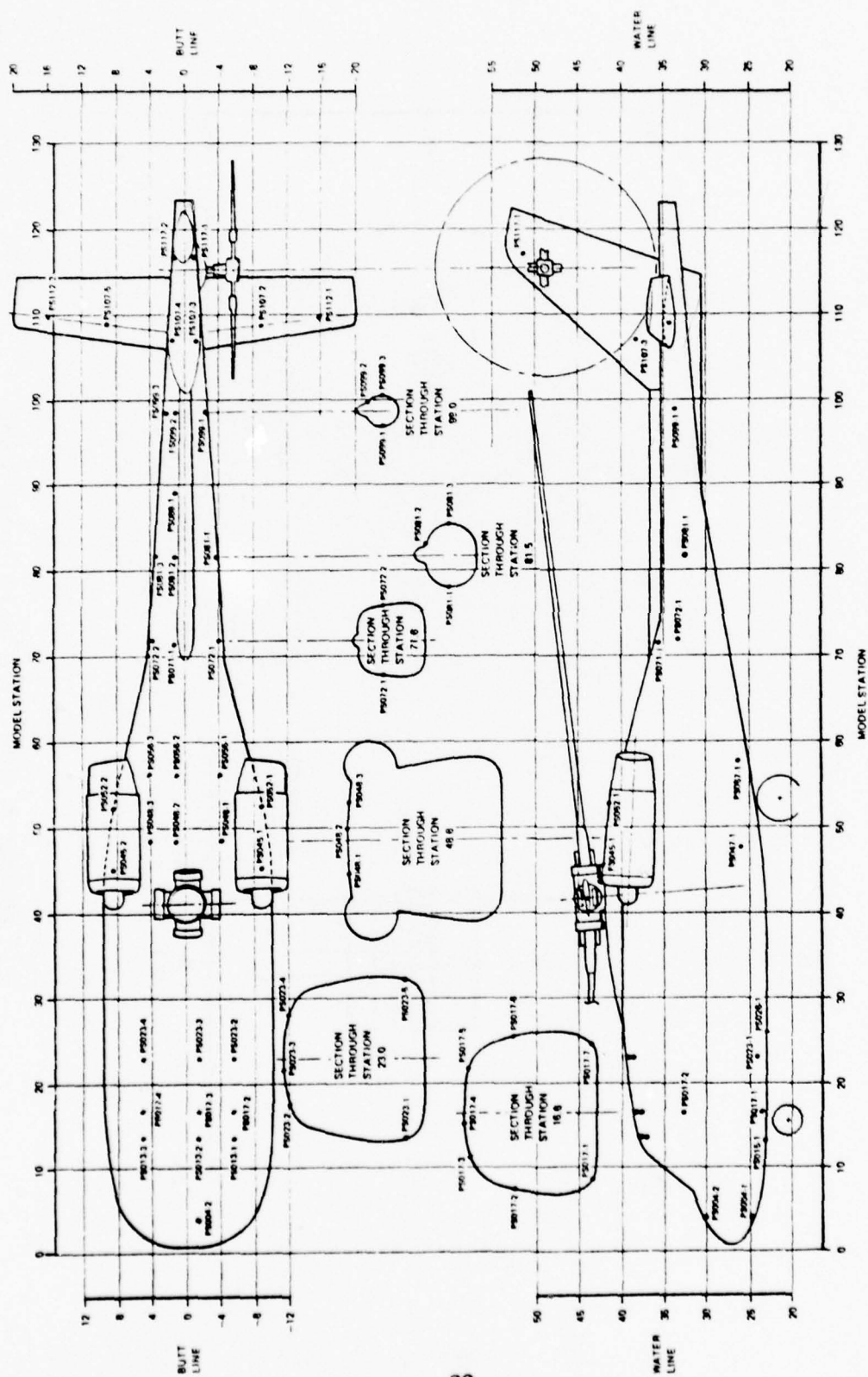
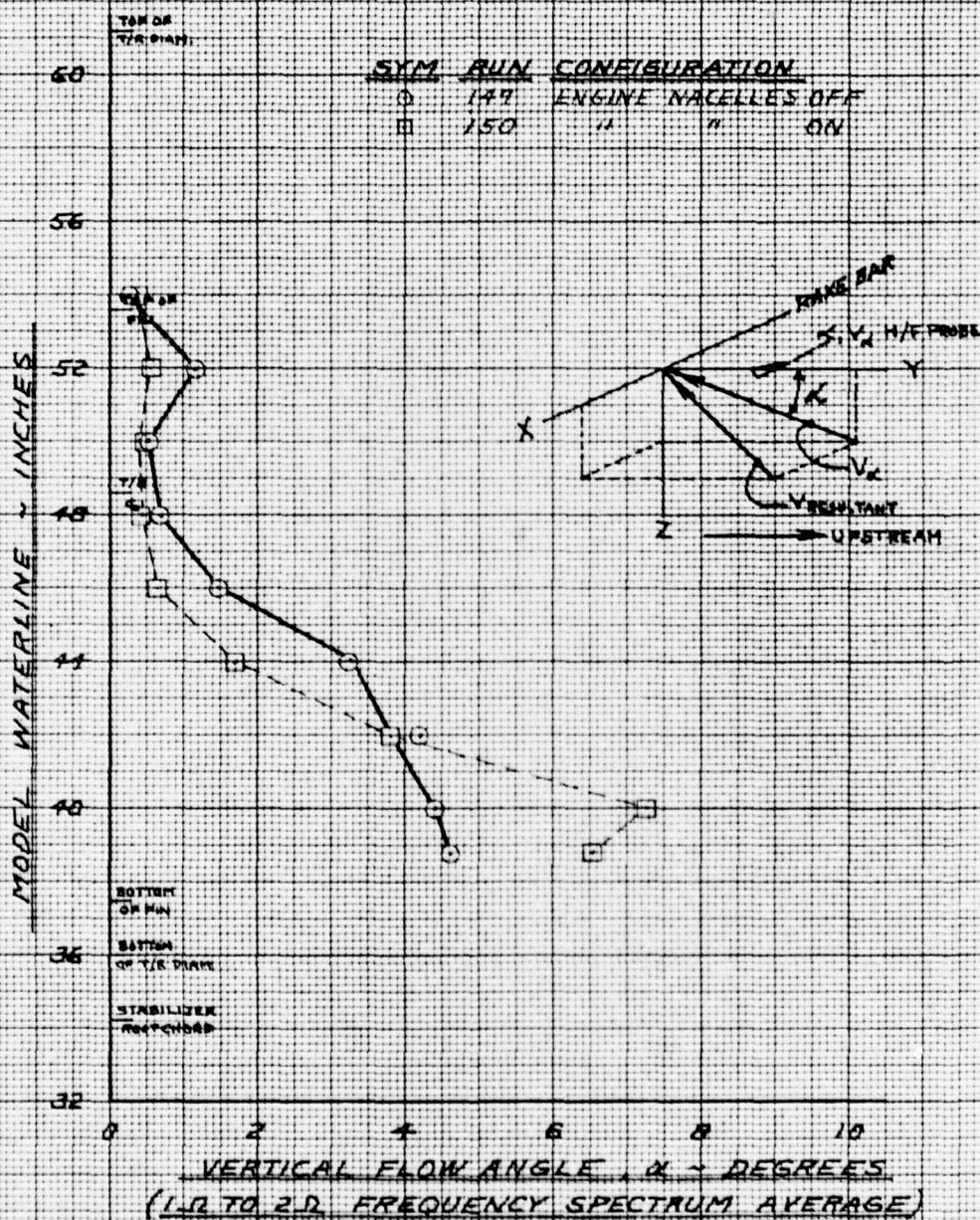


FIGURE 7 -1/4.85 SCALE MODEL GEOMETRY AND
SURFACE PRESSURE TRANSDUCER LOCATIONS

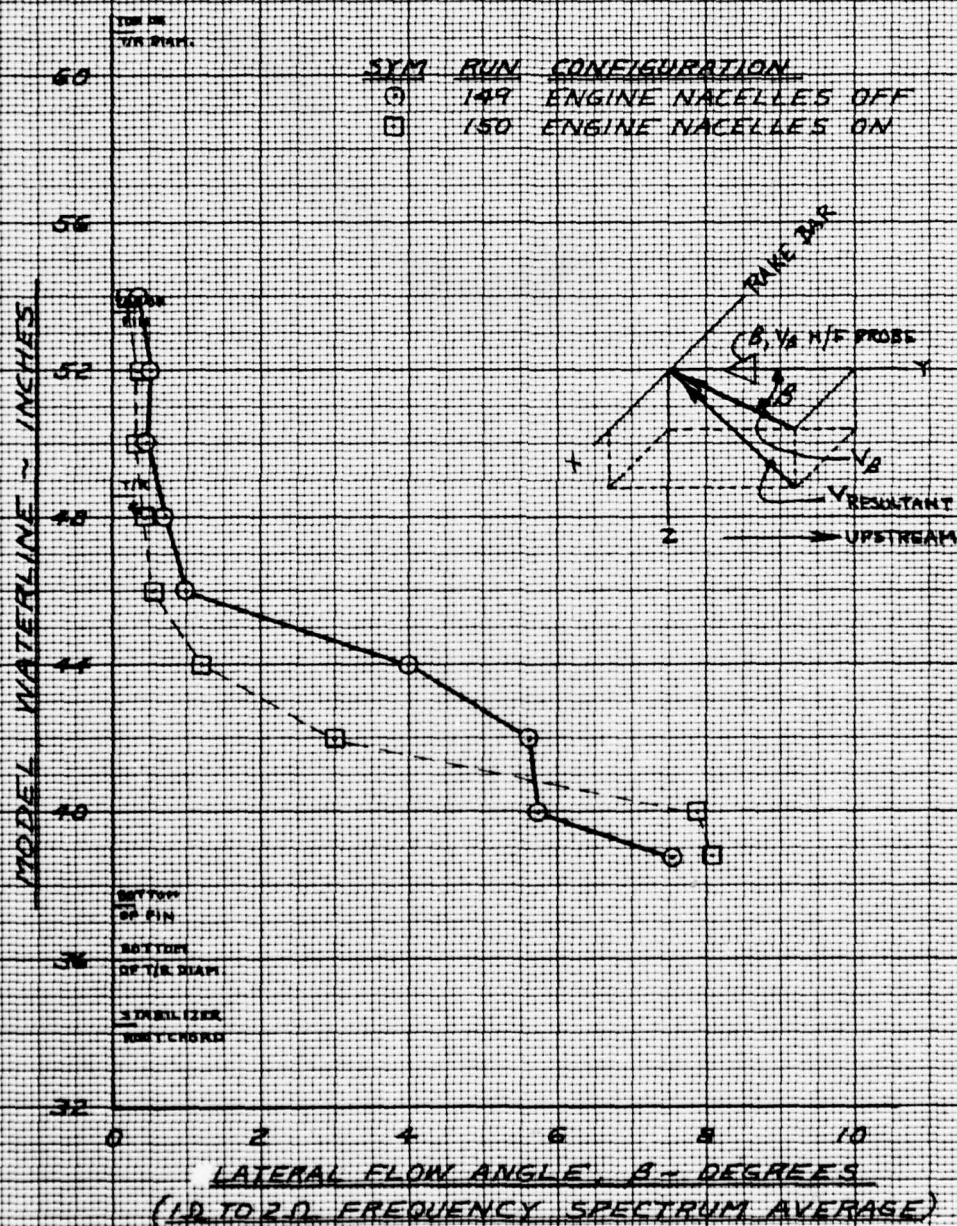
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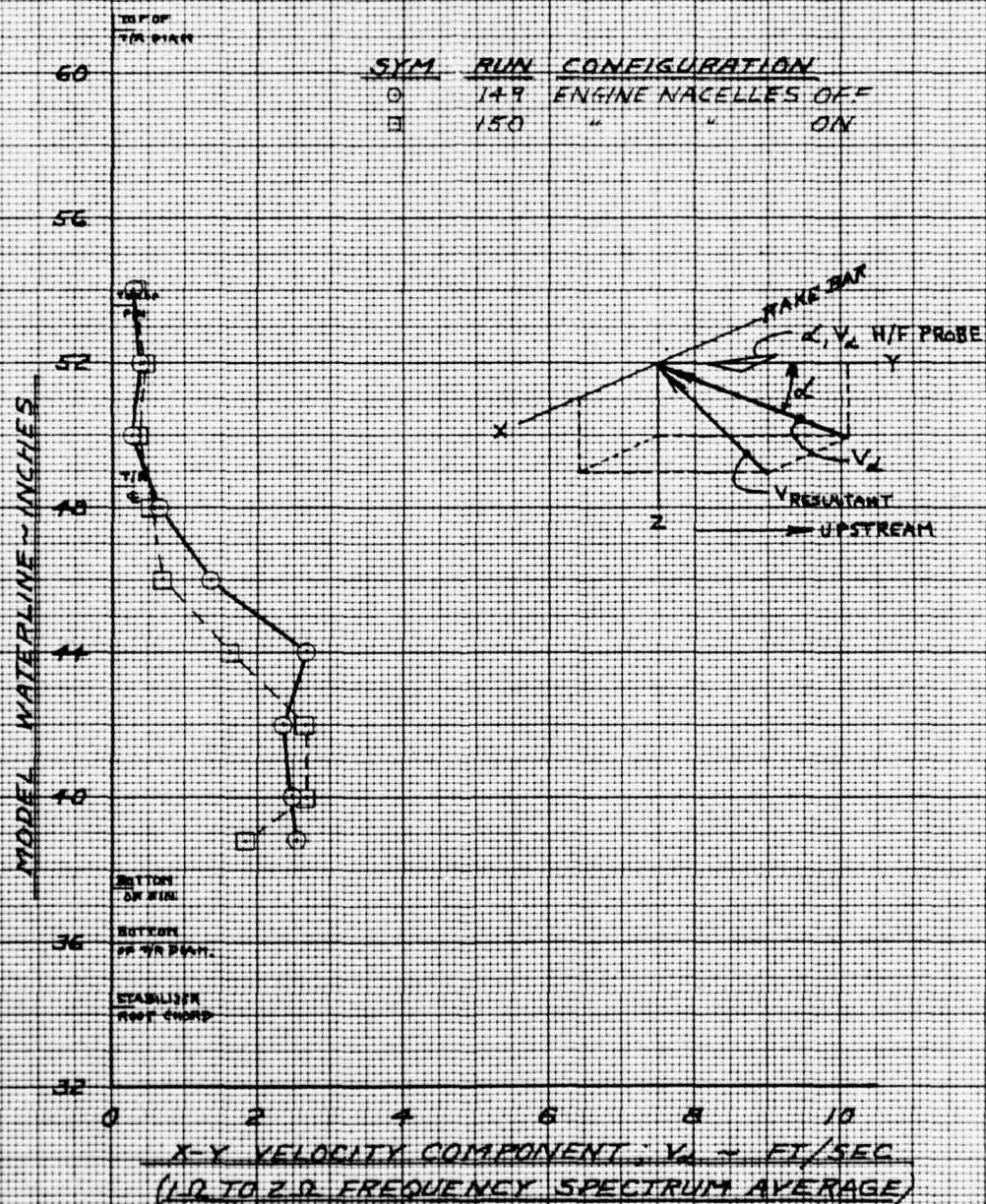
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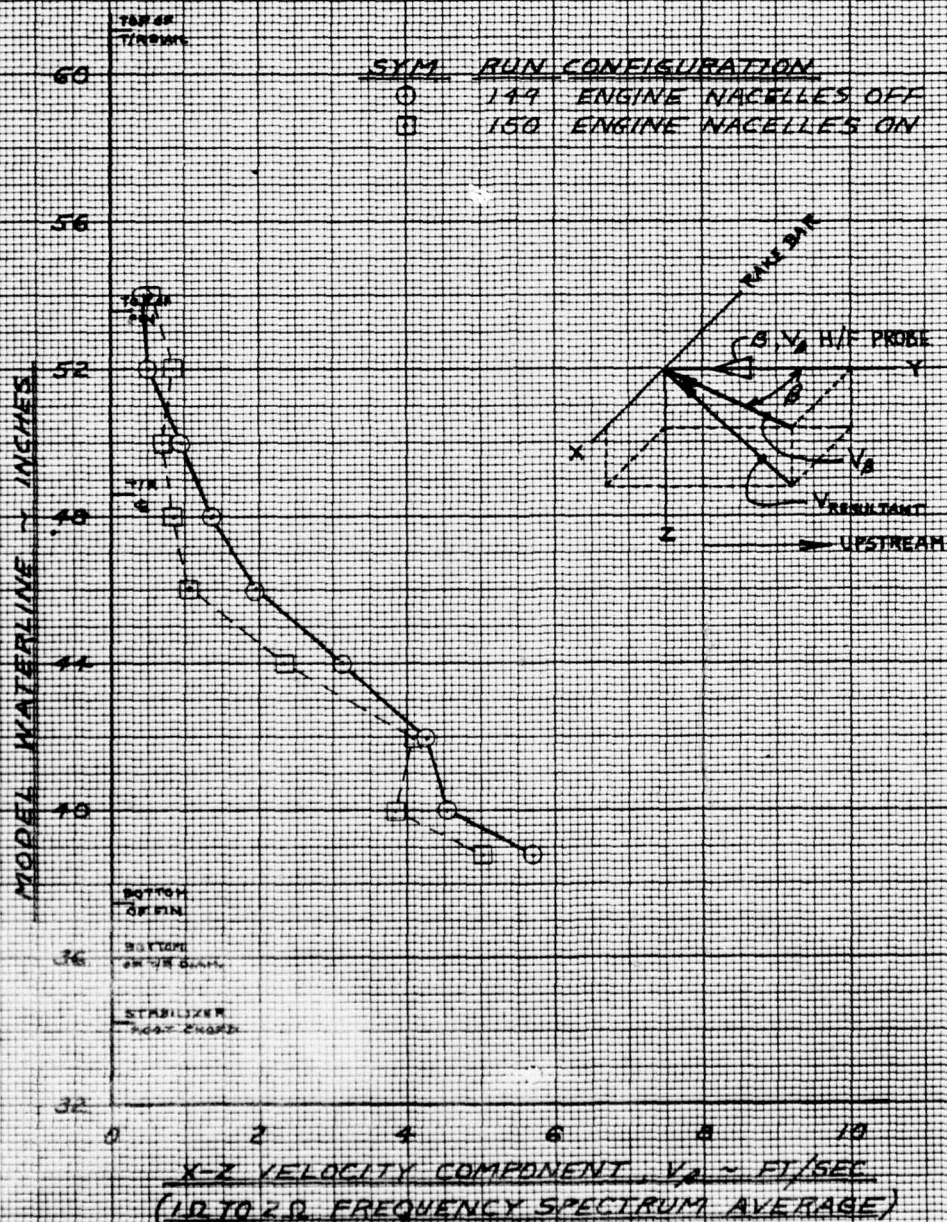
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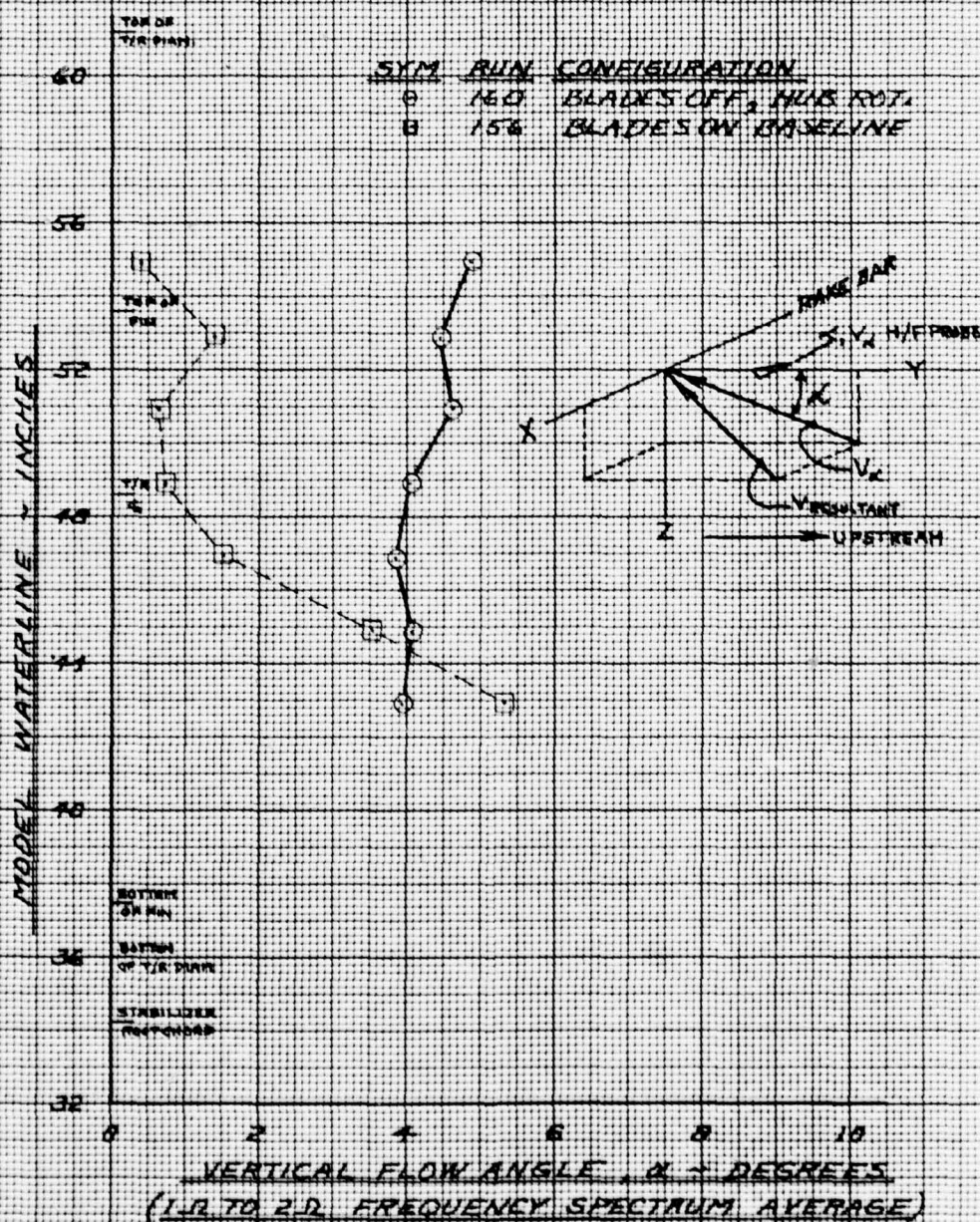
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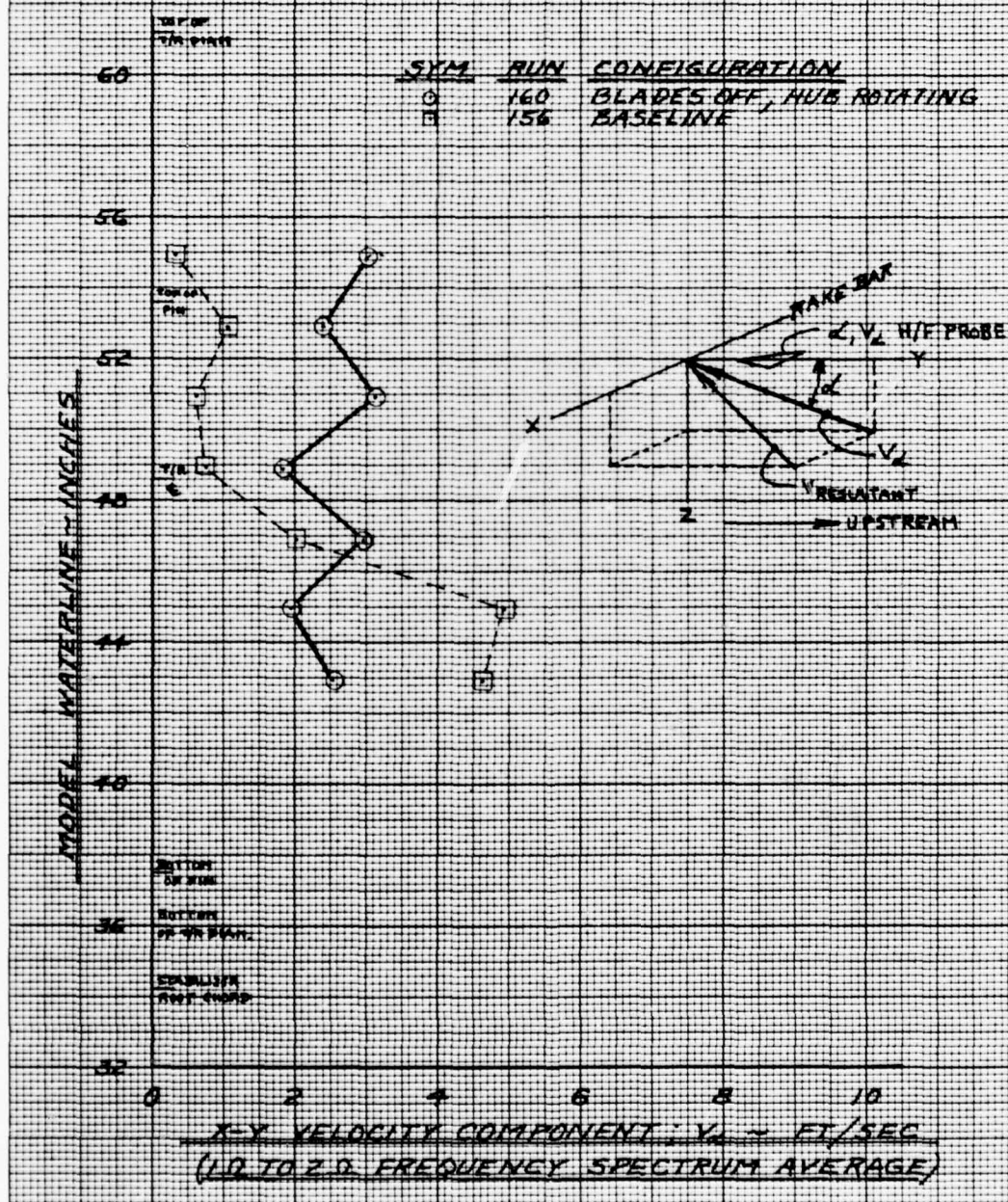


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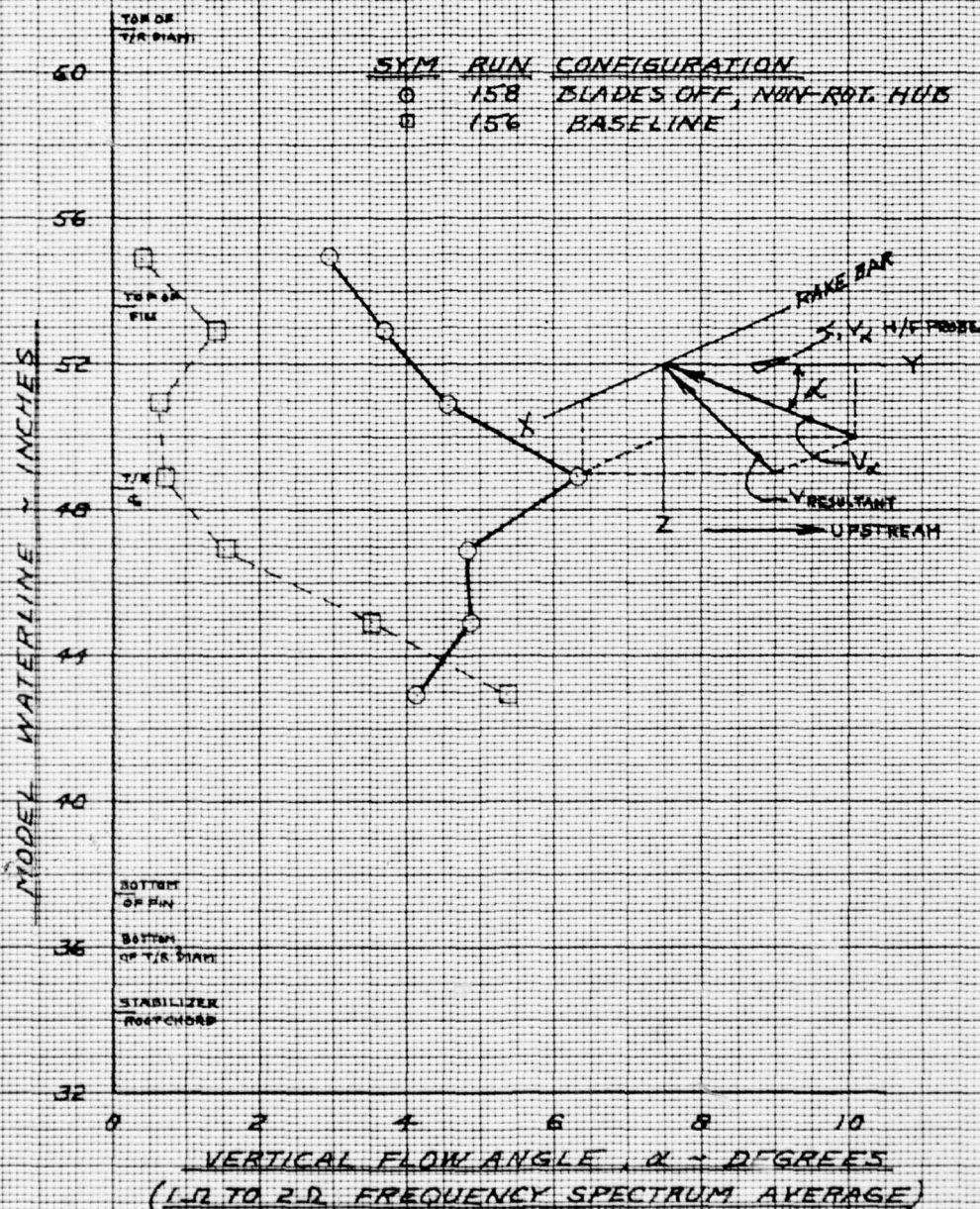


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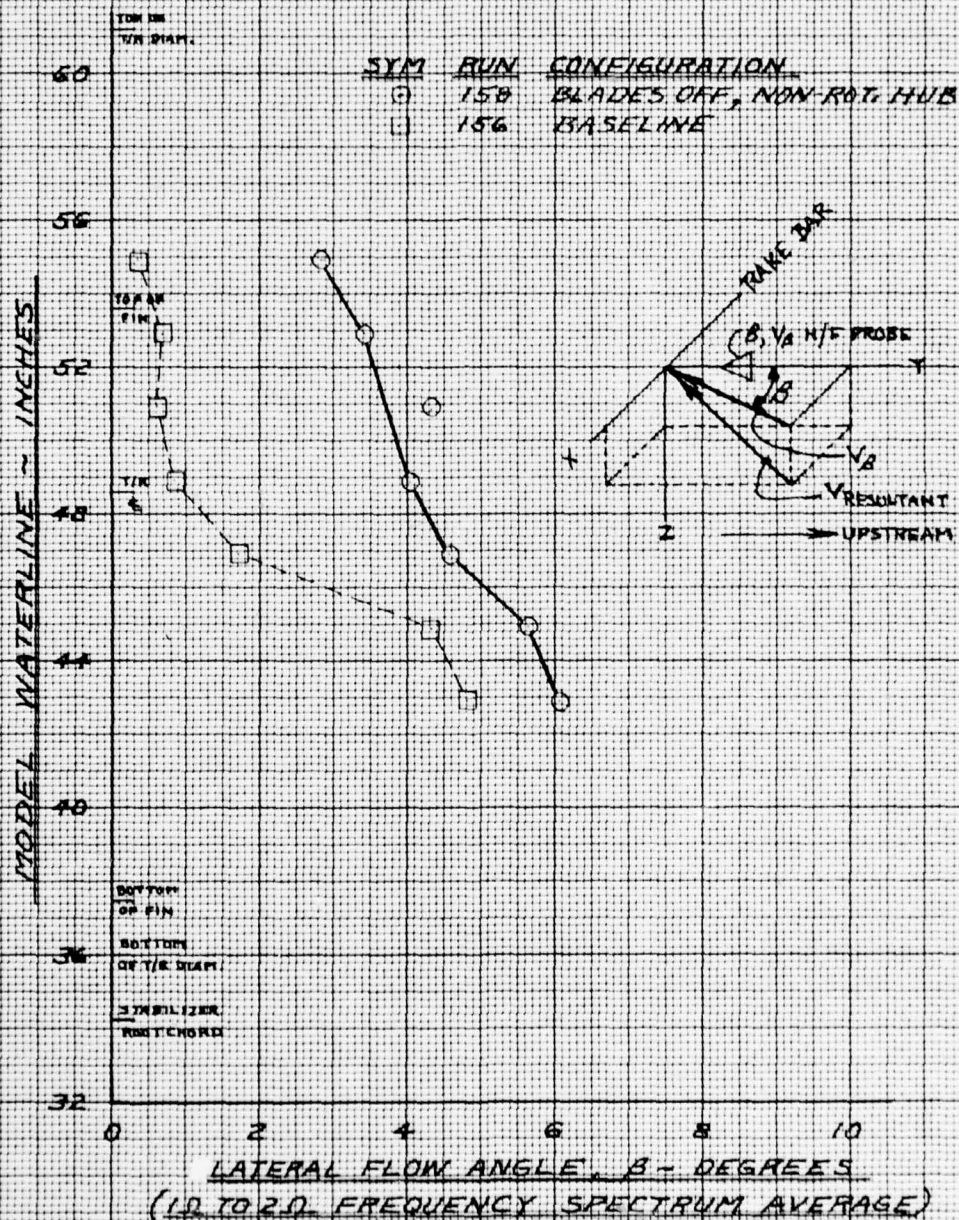
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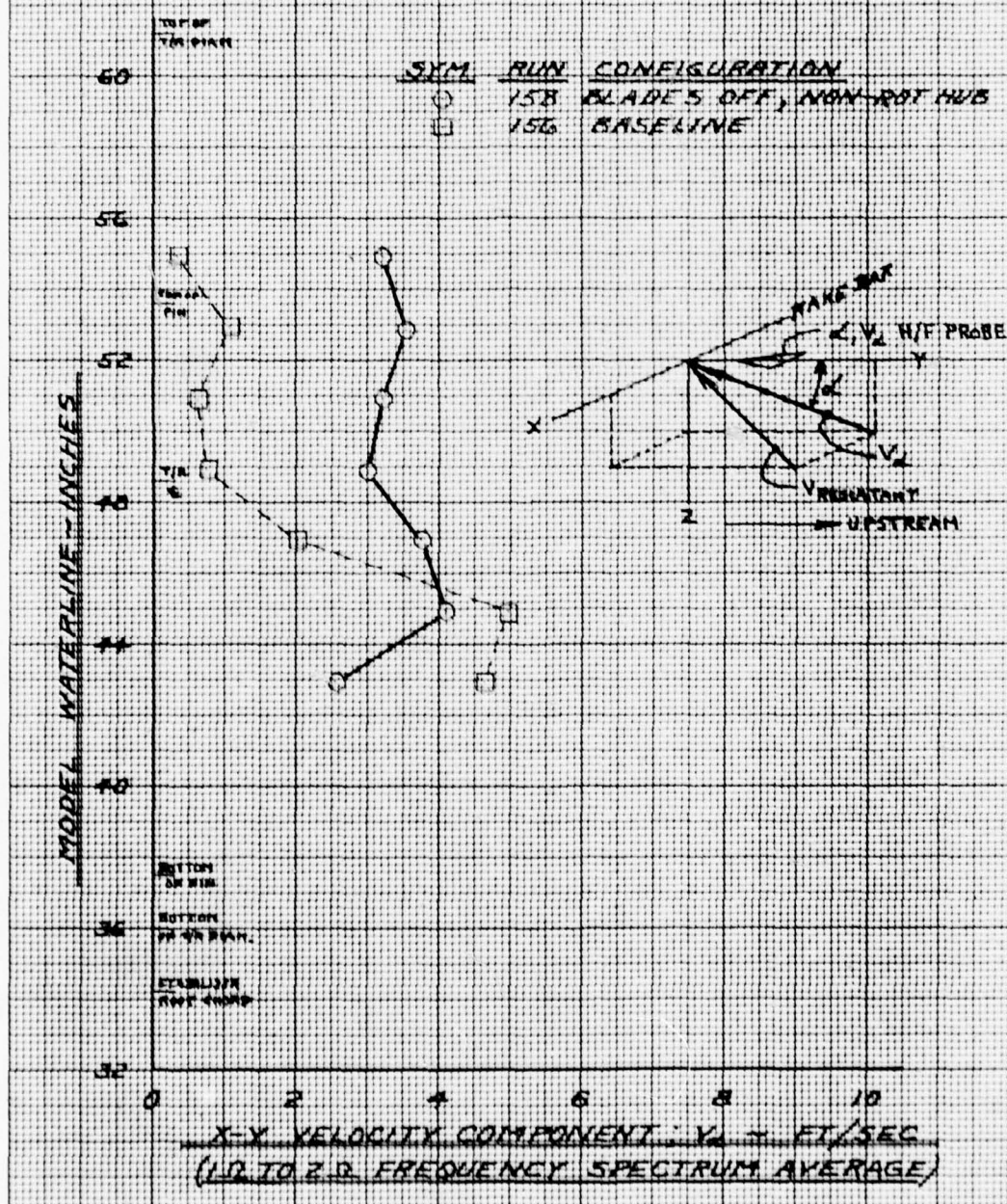
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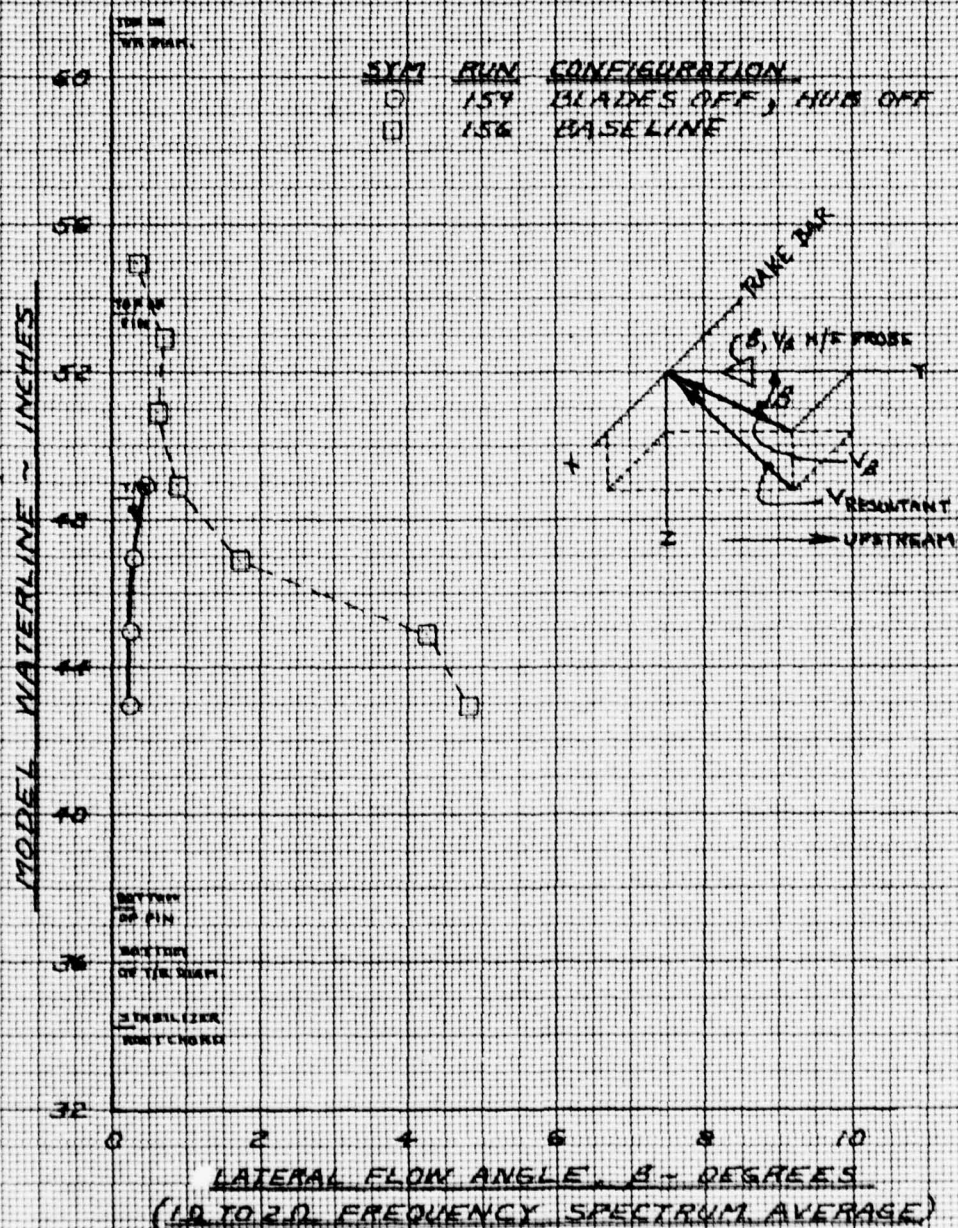


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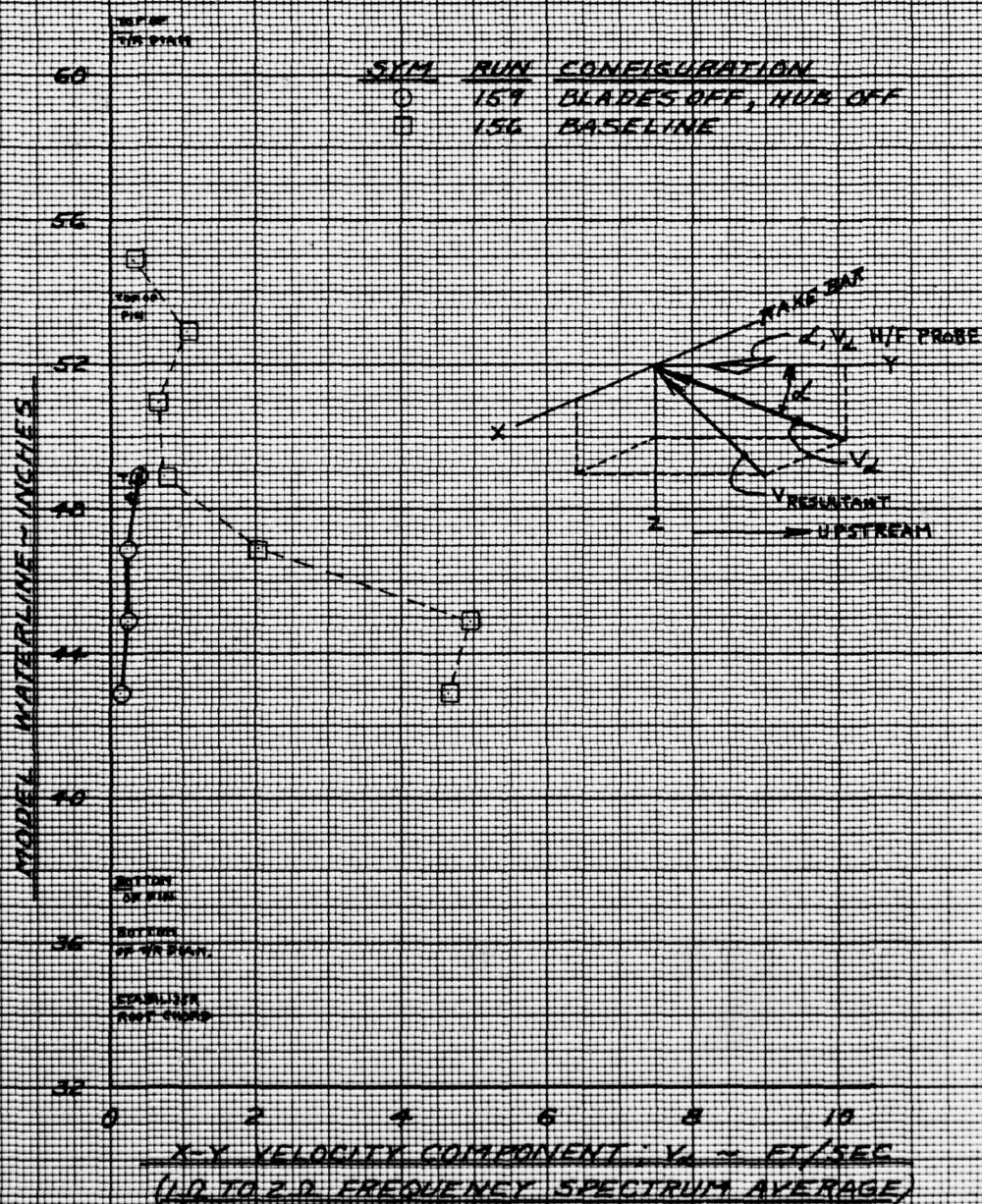
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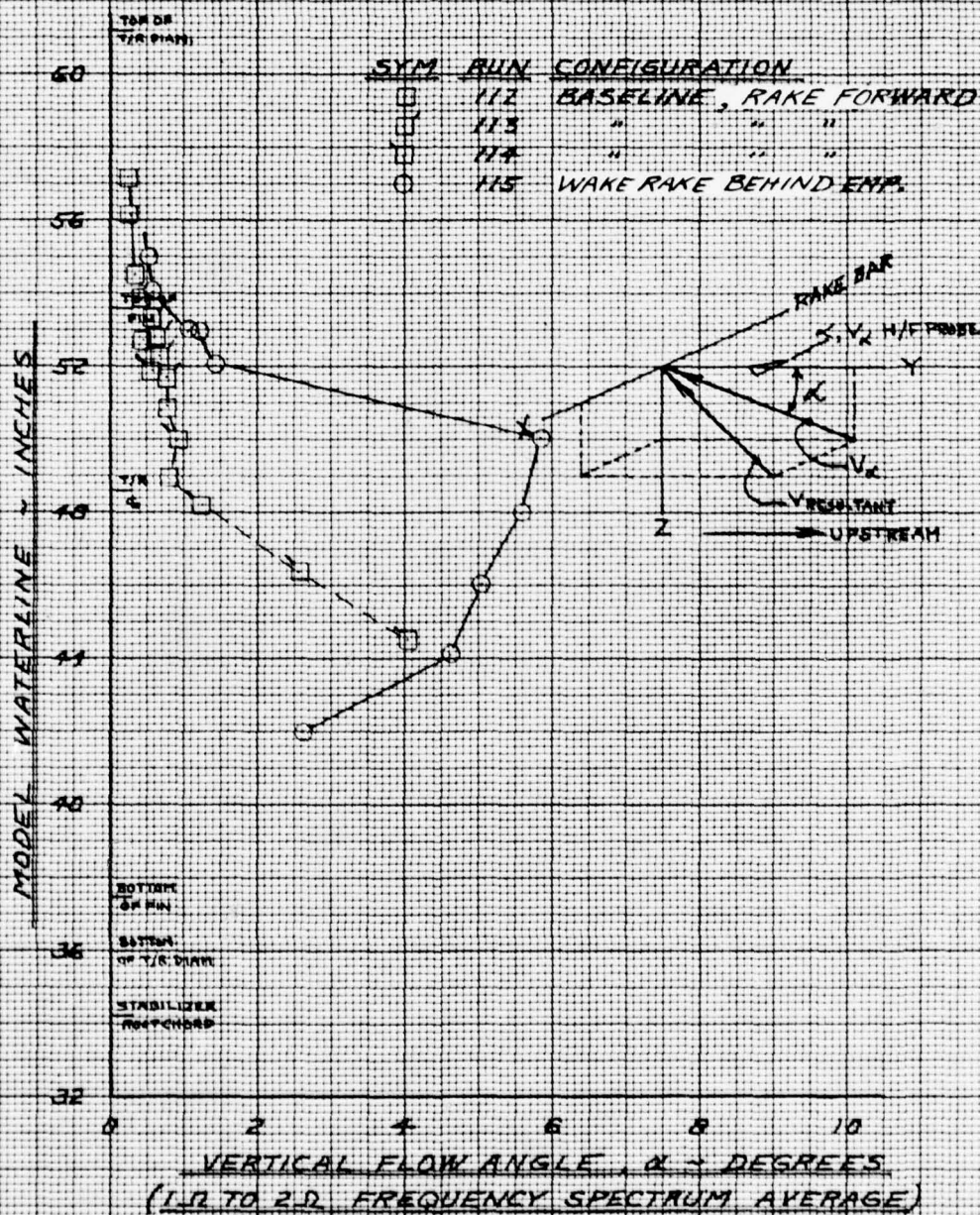


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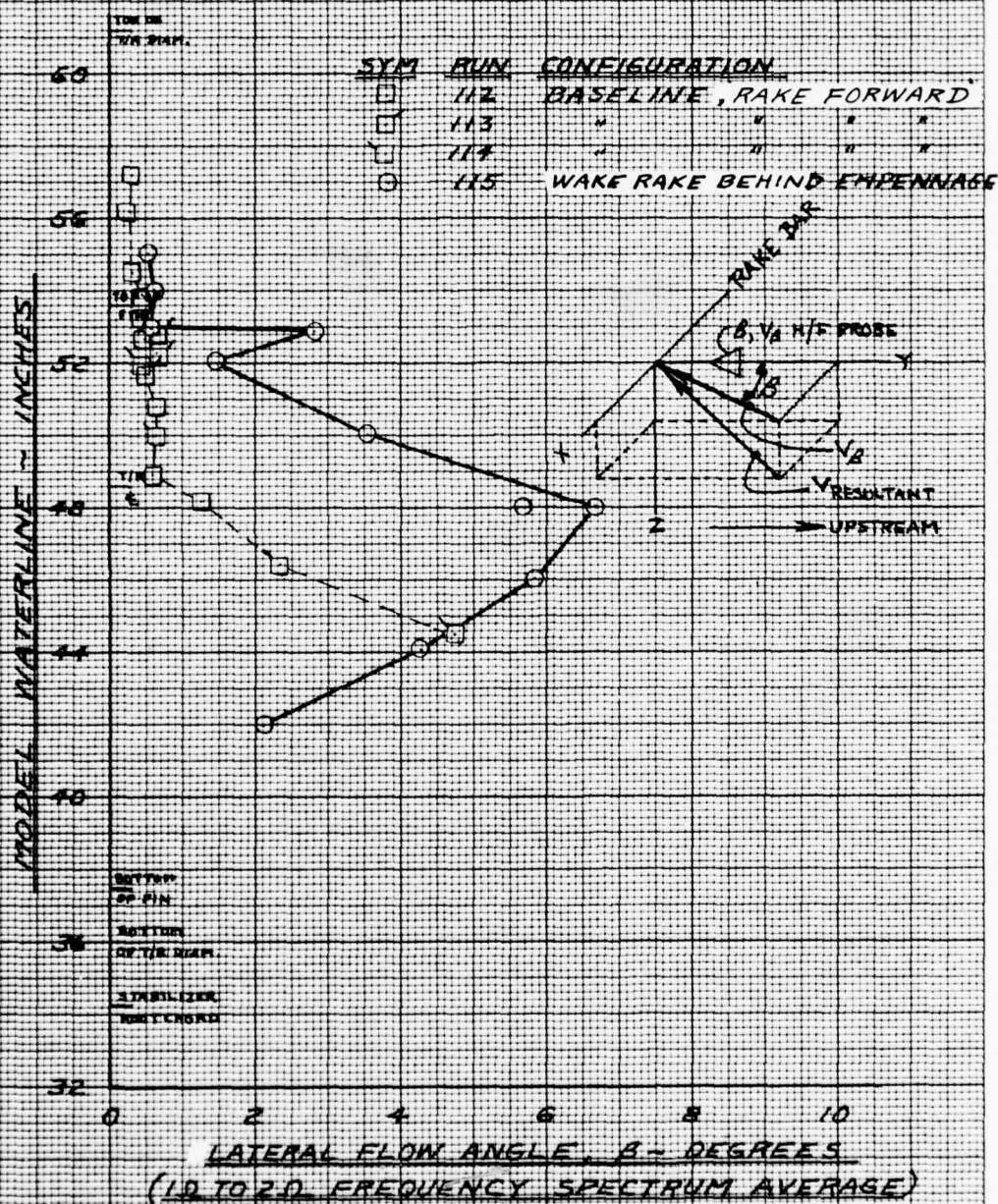
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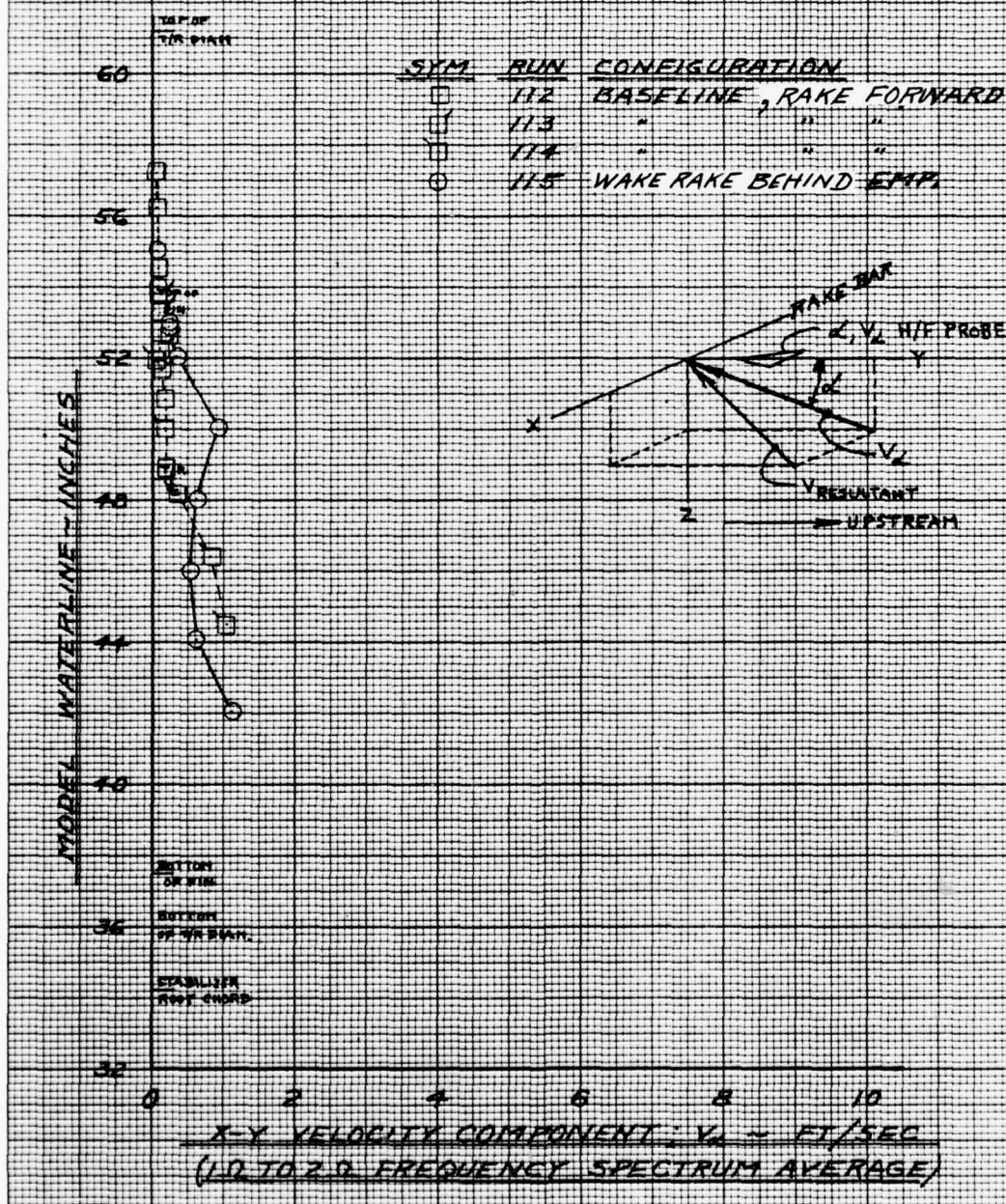
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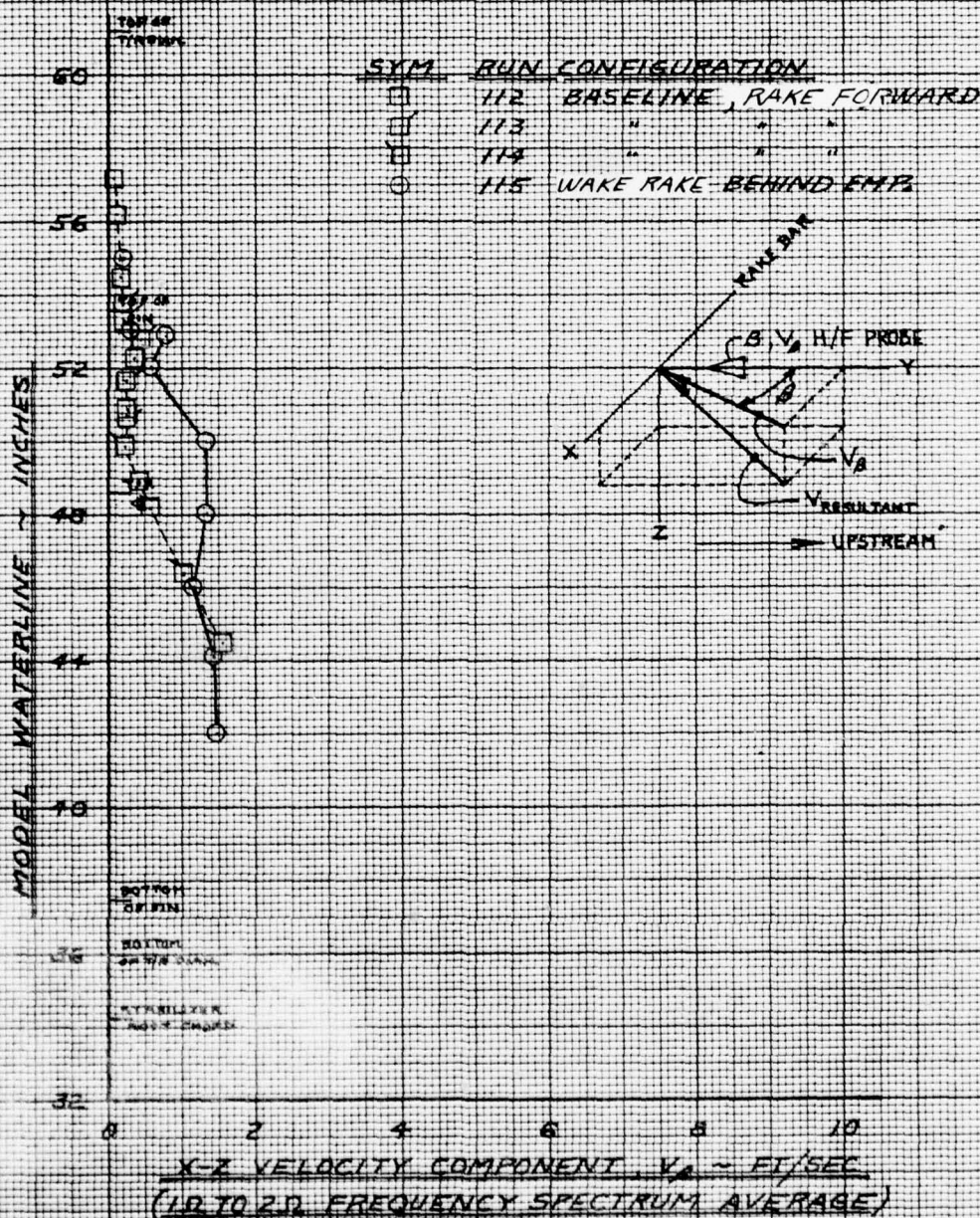
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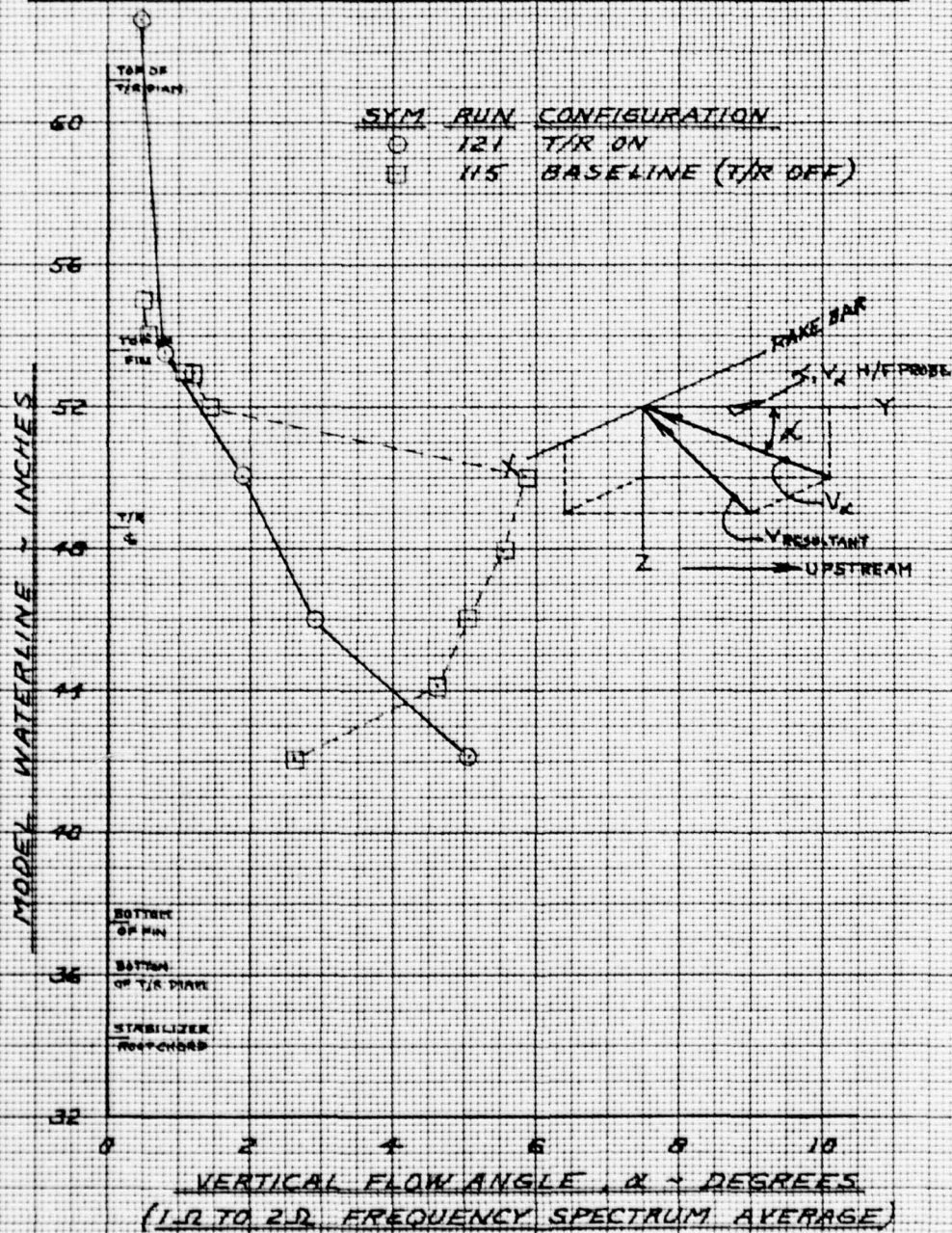
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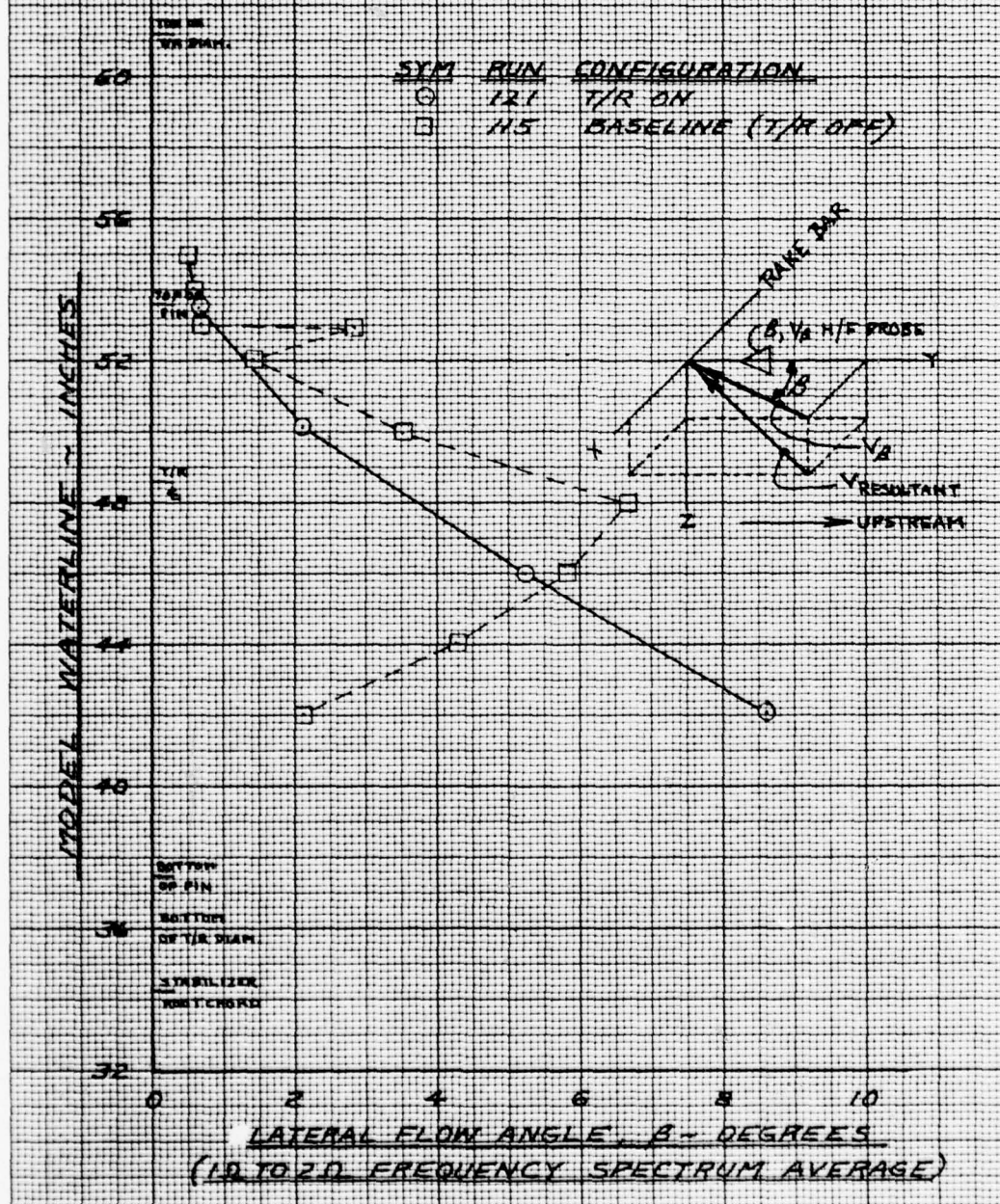
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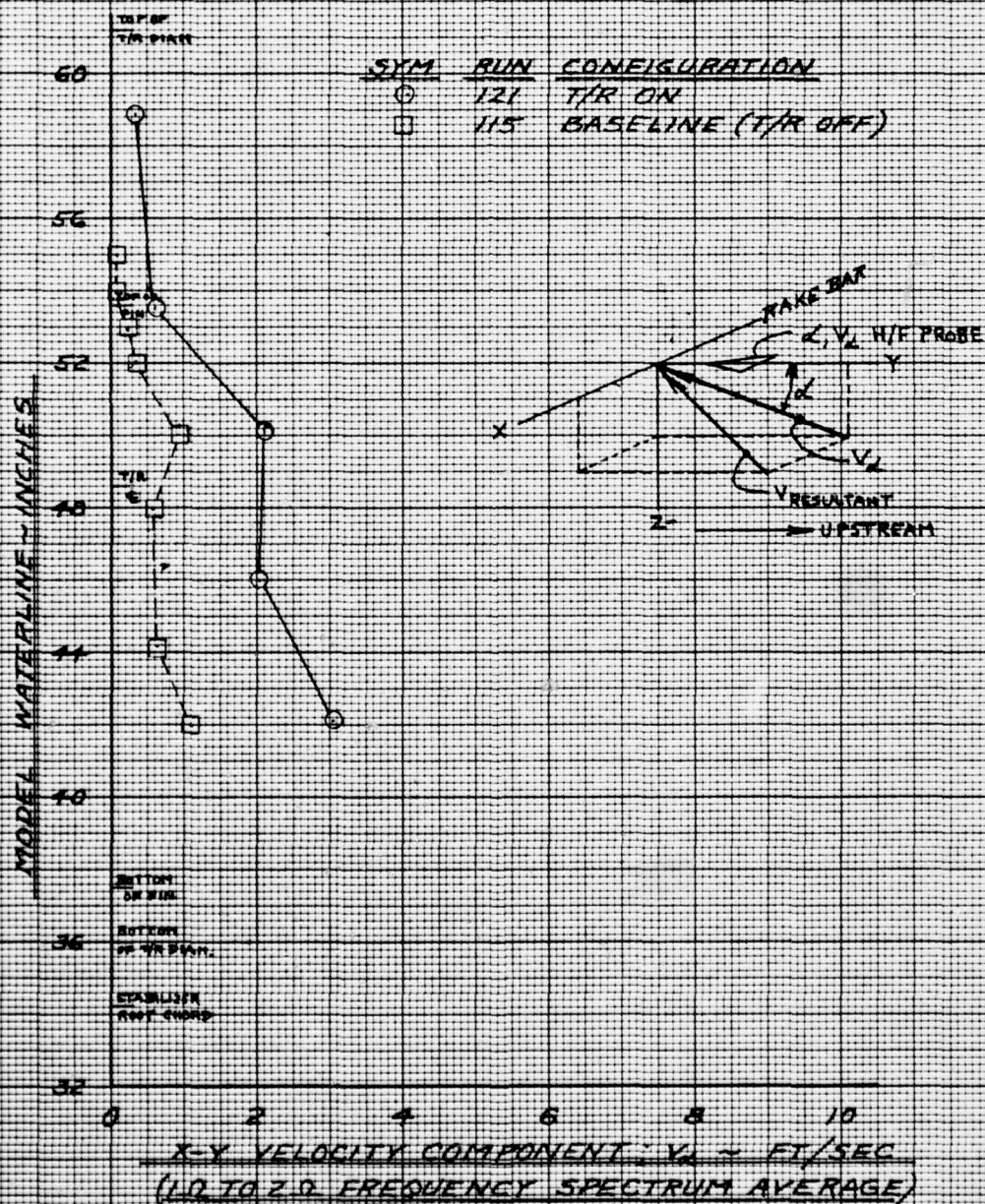
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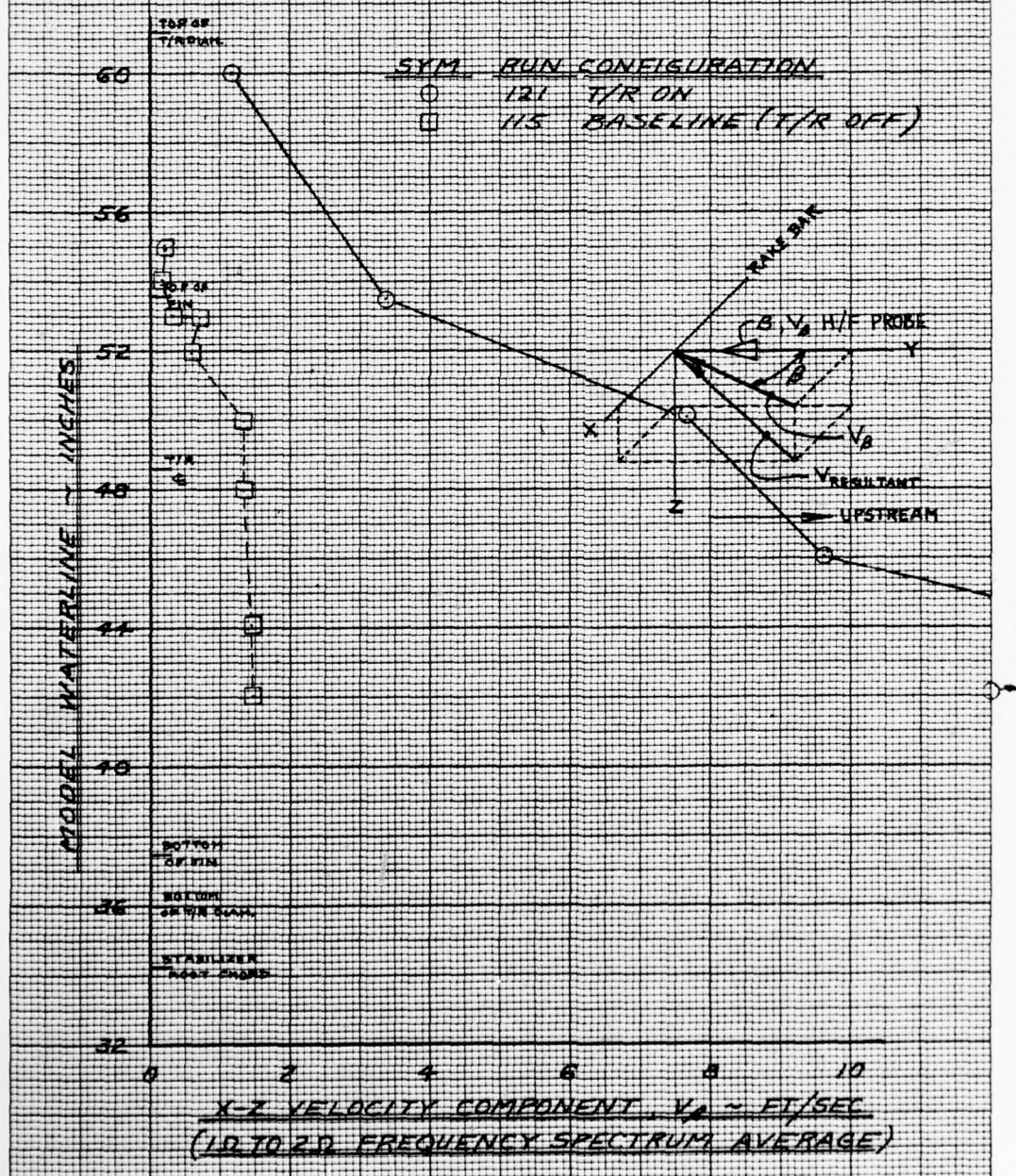
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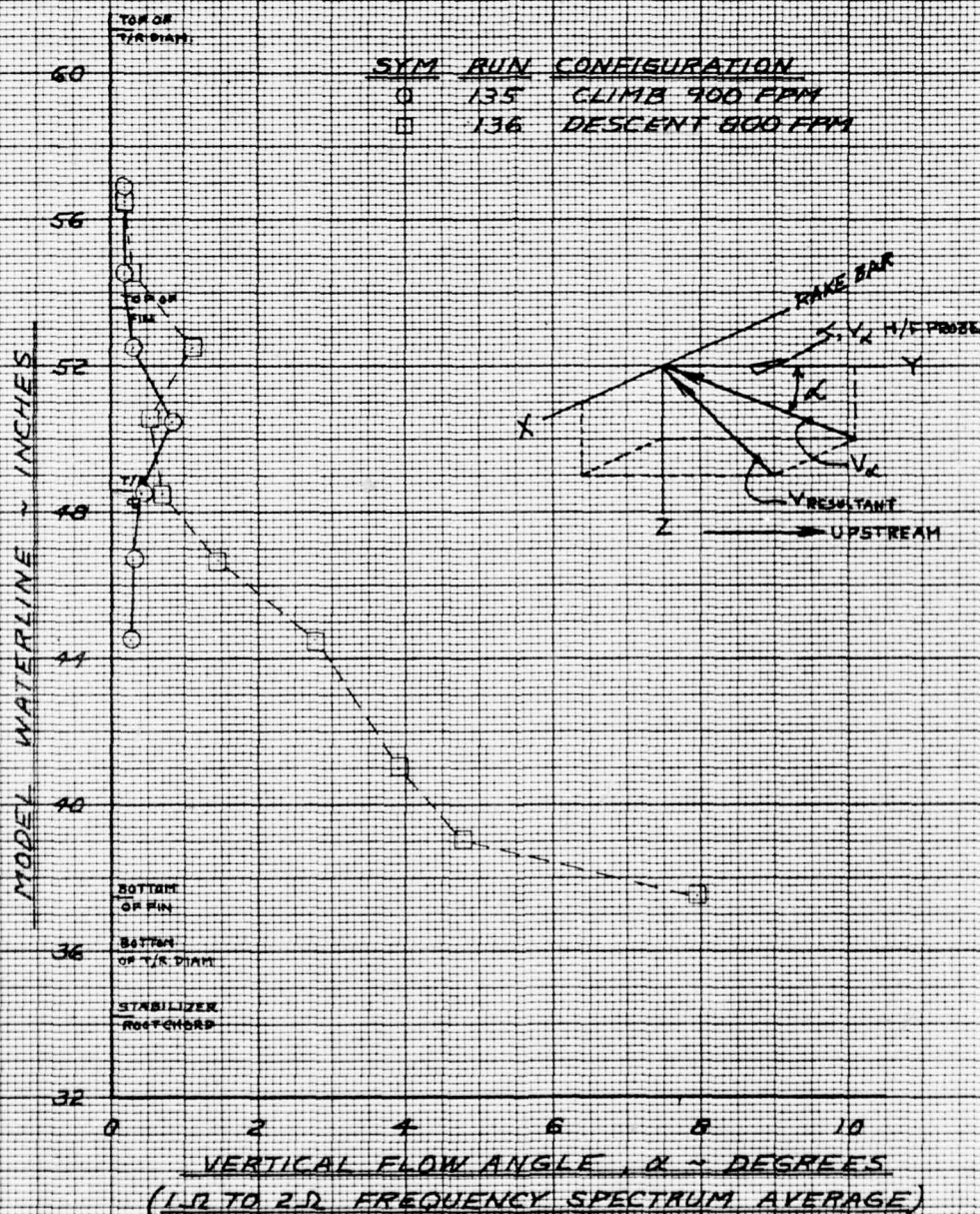
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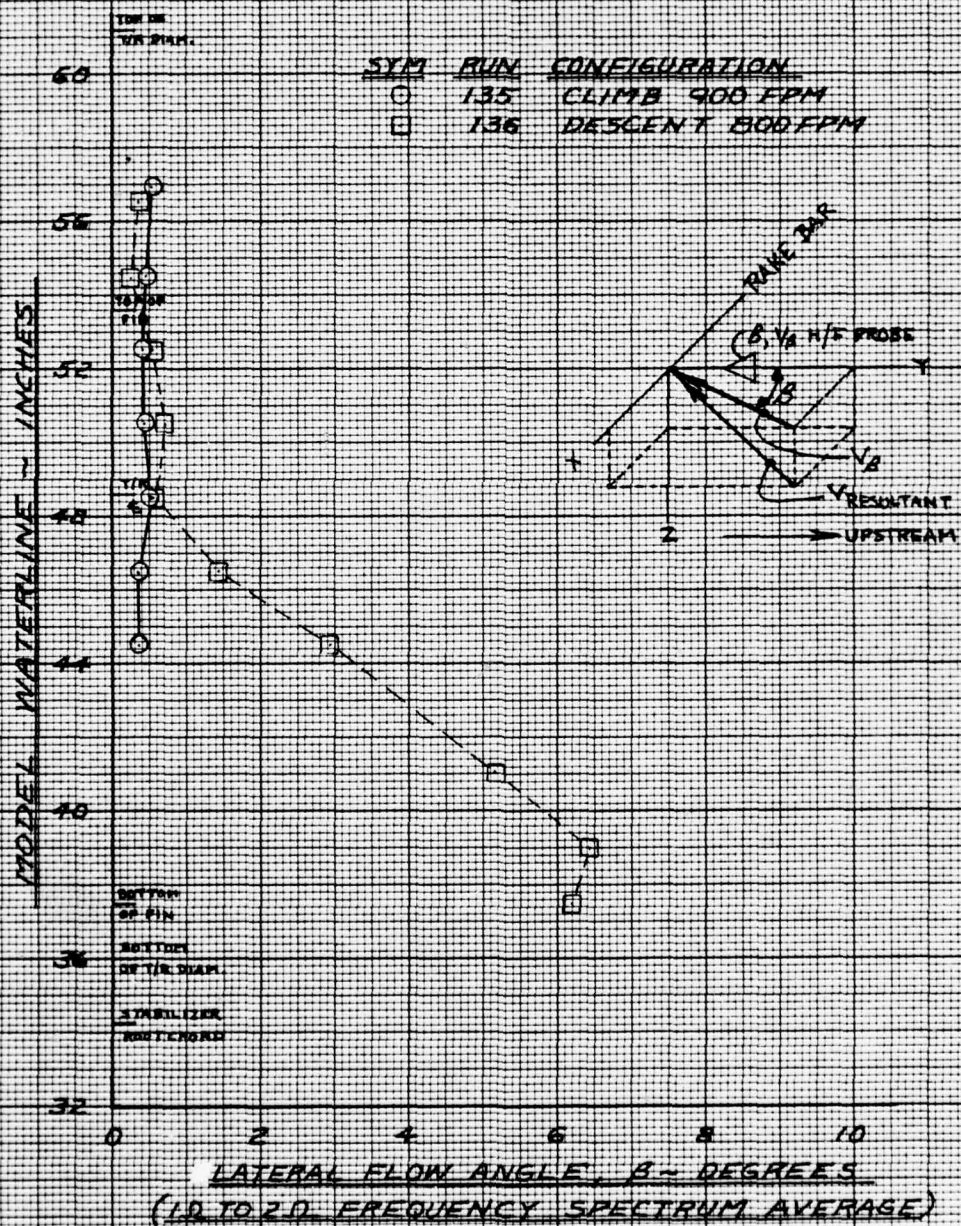


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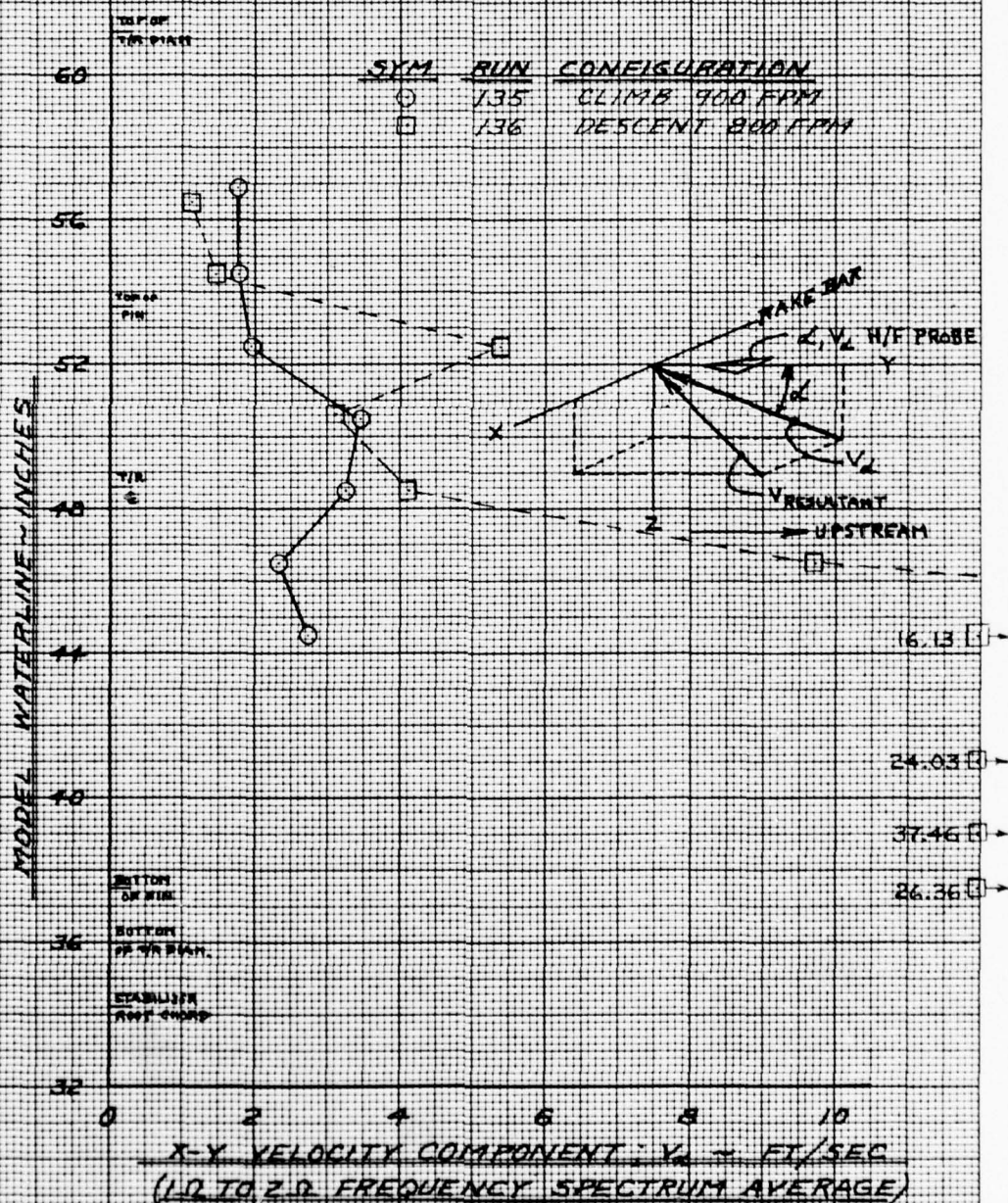


UNSTEADY WAKE LATERAL FLOW ANGLES



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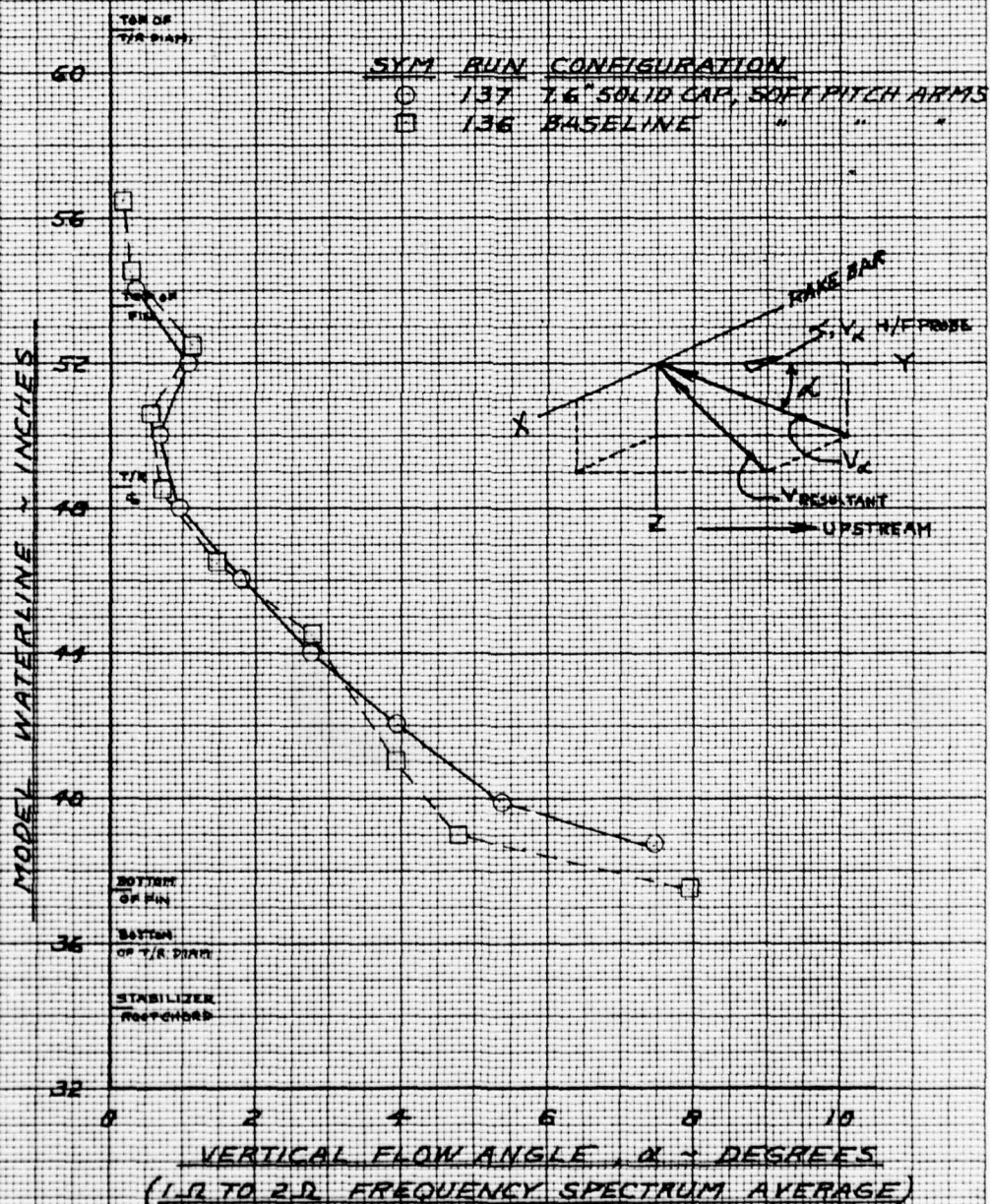


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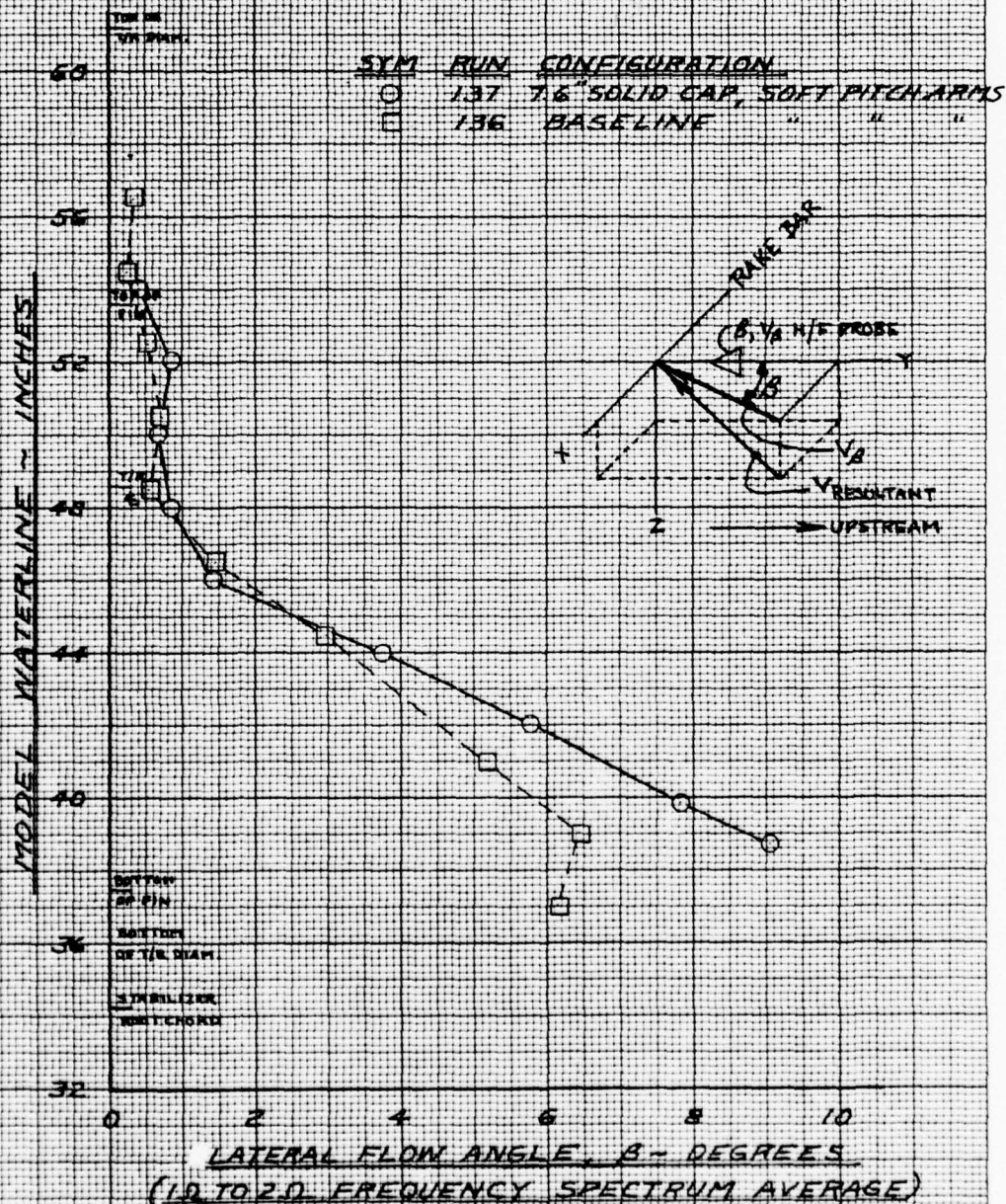
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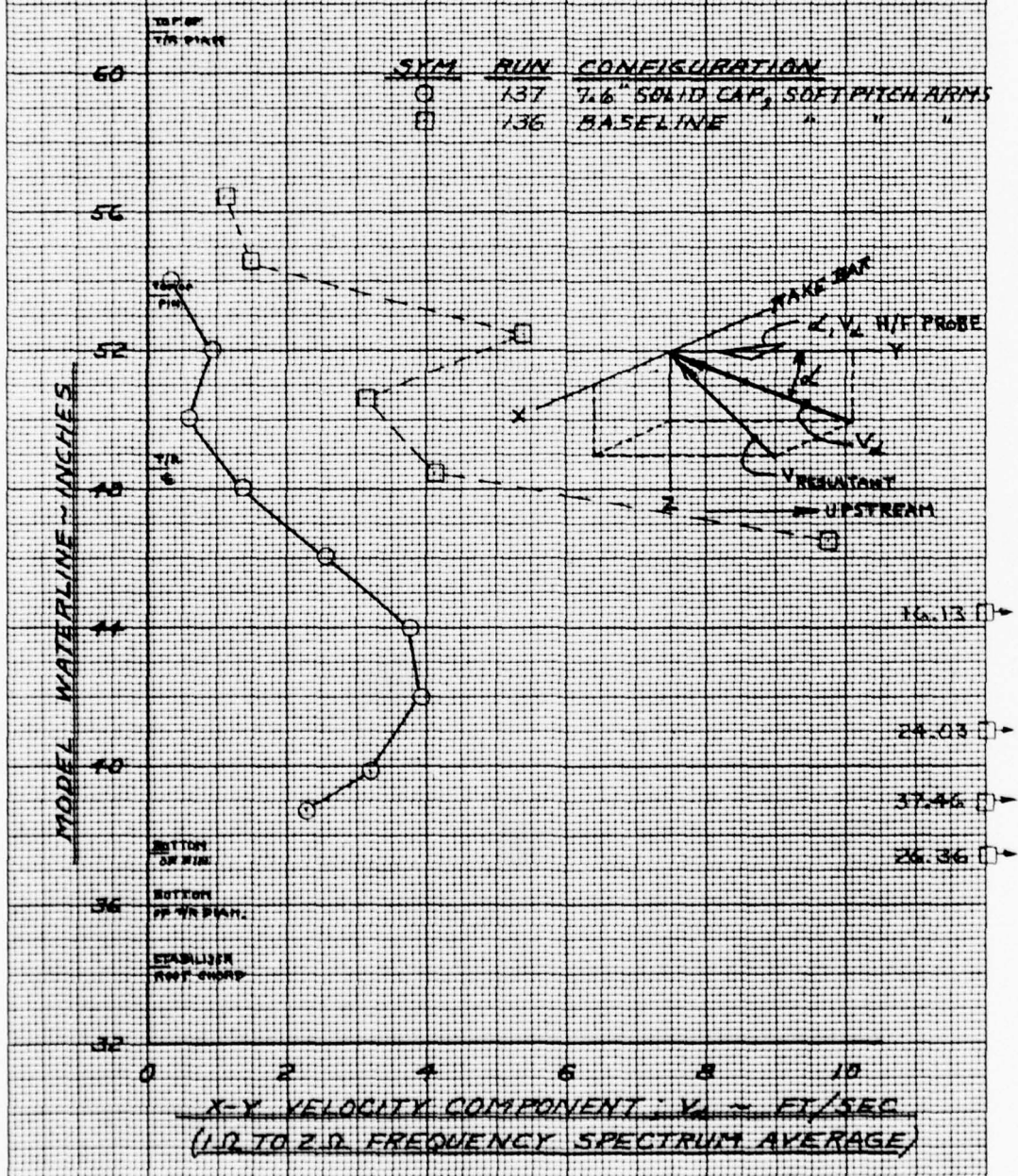
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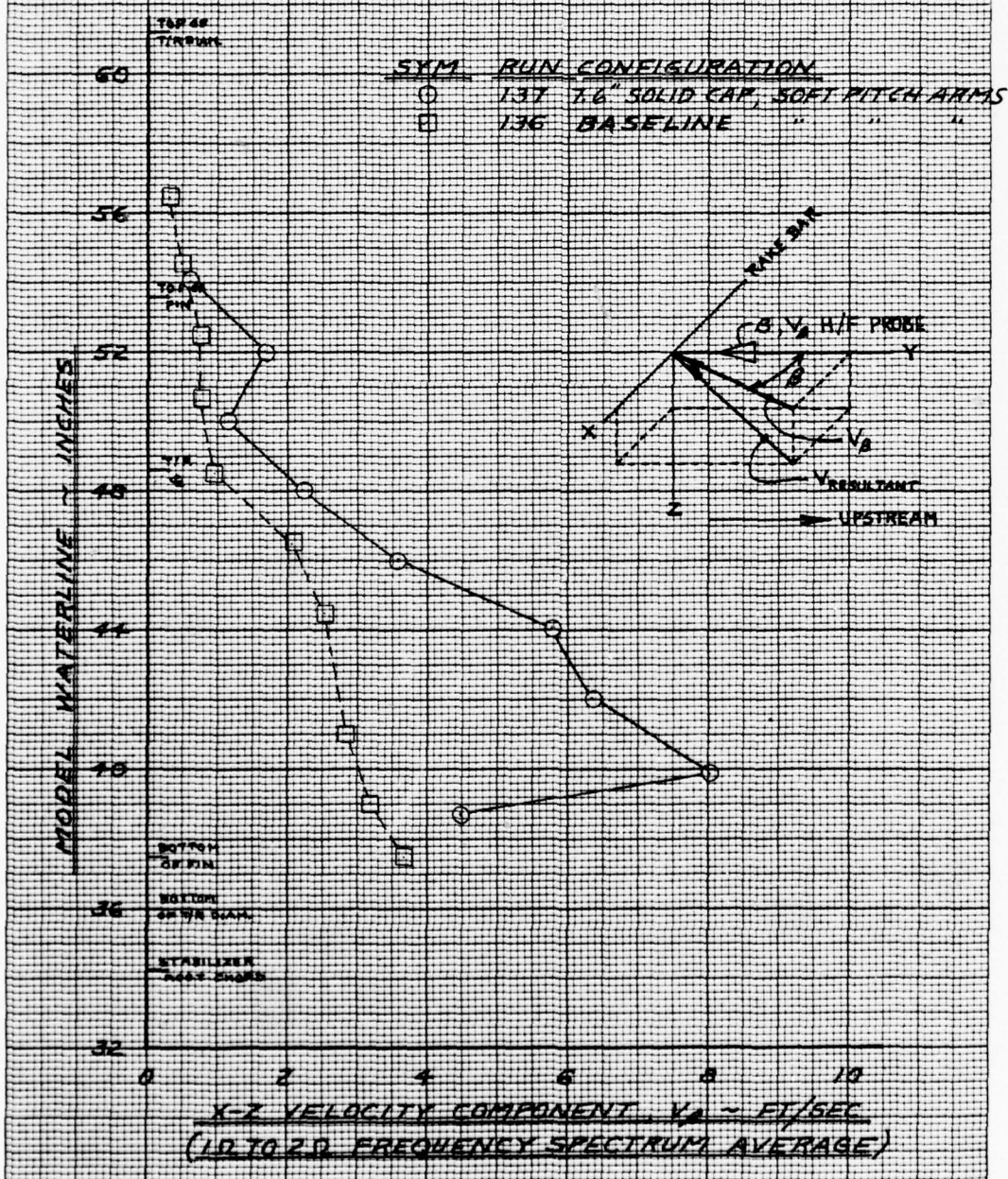
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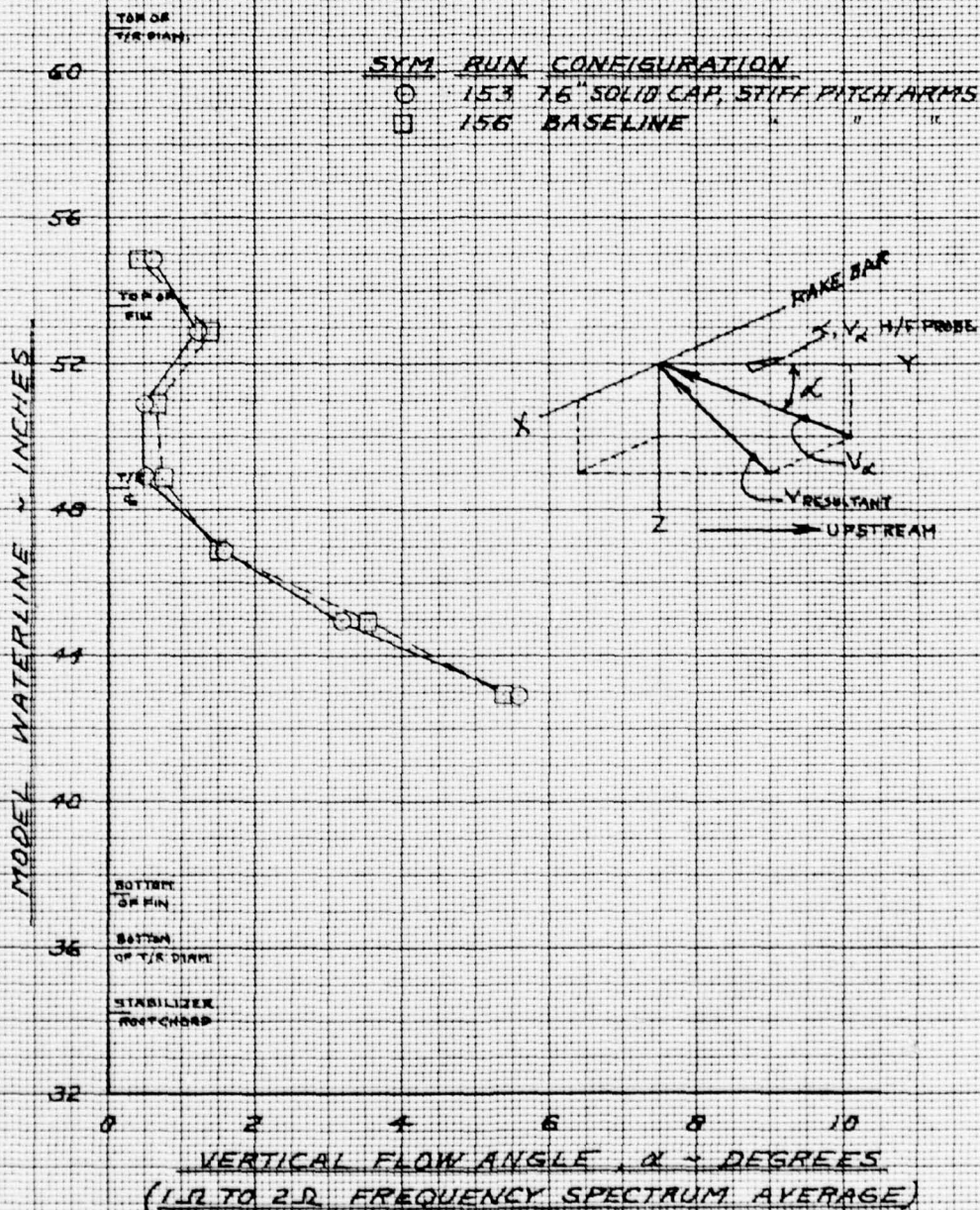
ROTOR/HUB WAKE MODIFICATION STUDIES

UNSTEADY WAKE X-Z VELOCITY COMPONENTS



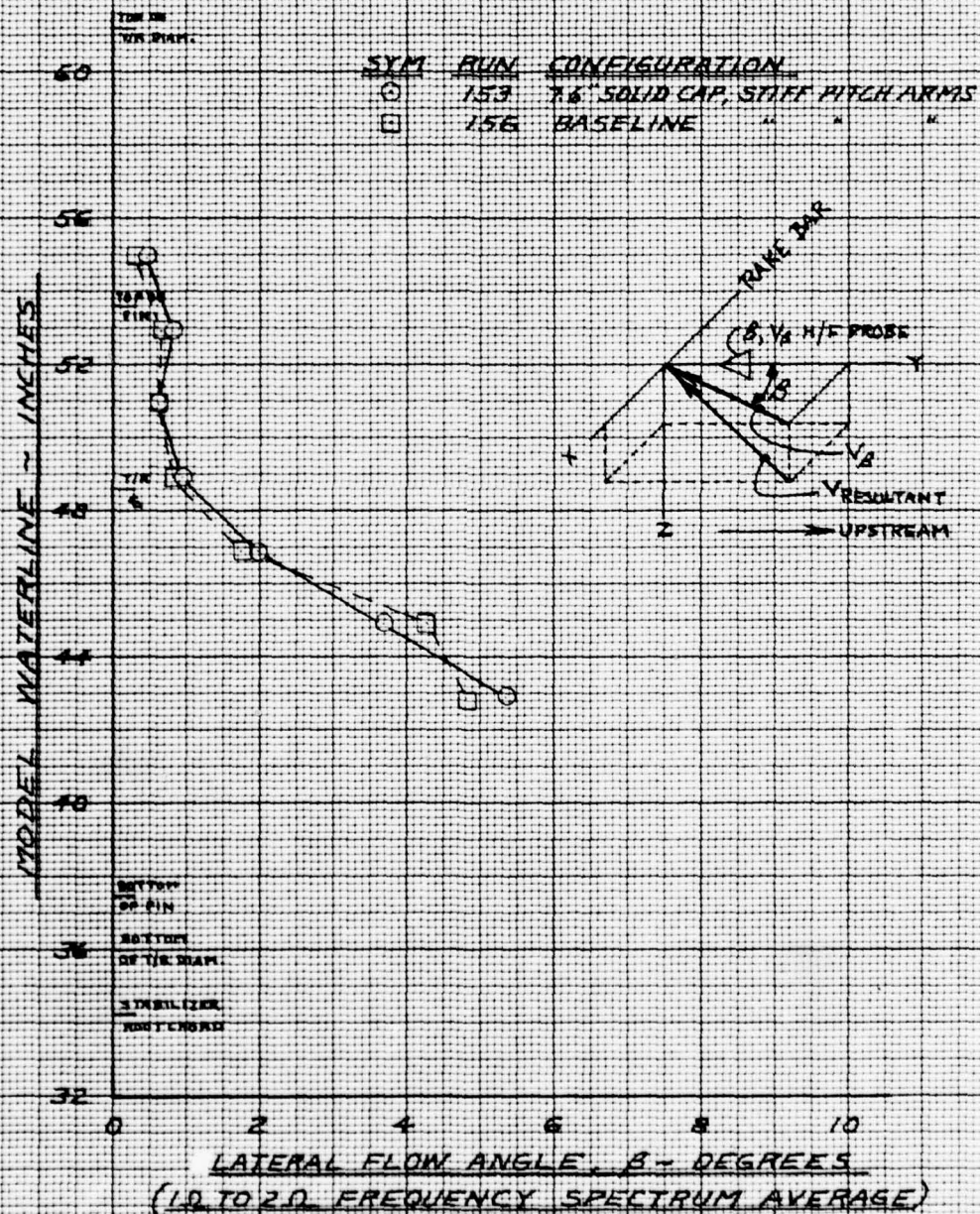
ROTOR/HUB WAKE MODIFICATION STUDIES

UNSTEADY WAKE VERTICAL FLOW ANGLES



ROTOR/HUB WAKE MODIFICATION STUDIES

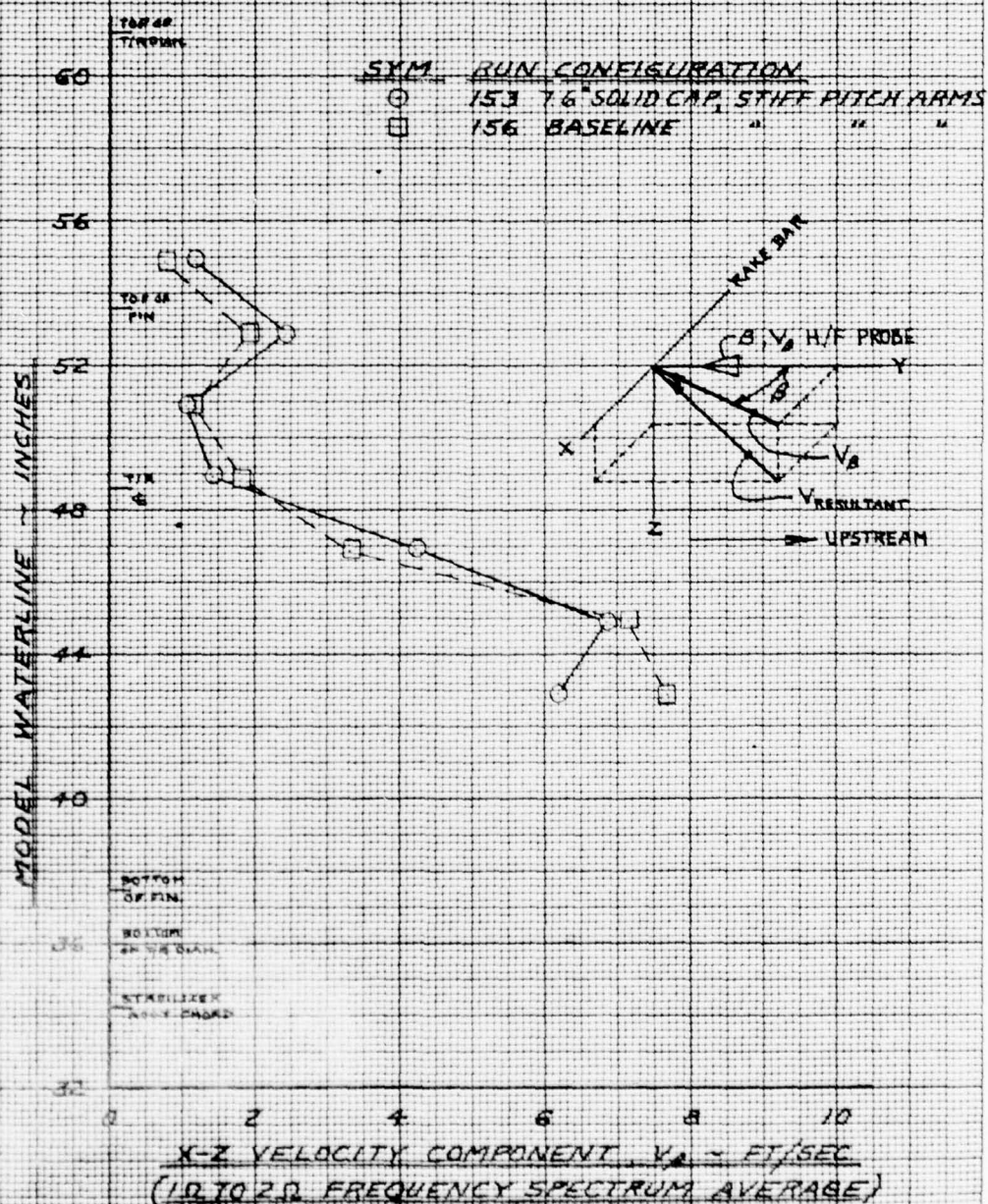
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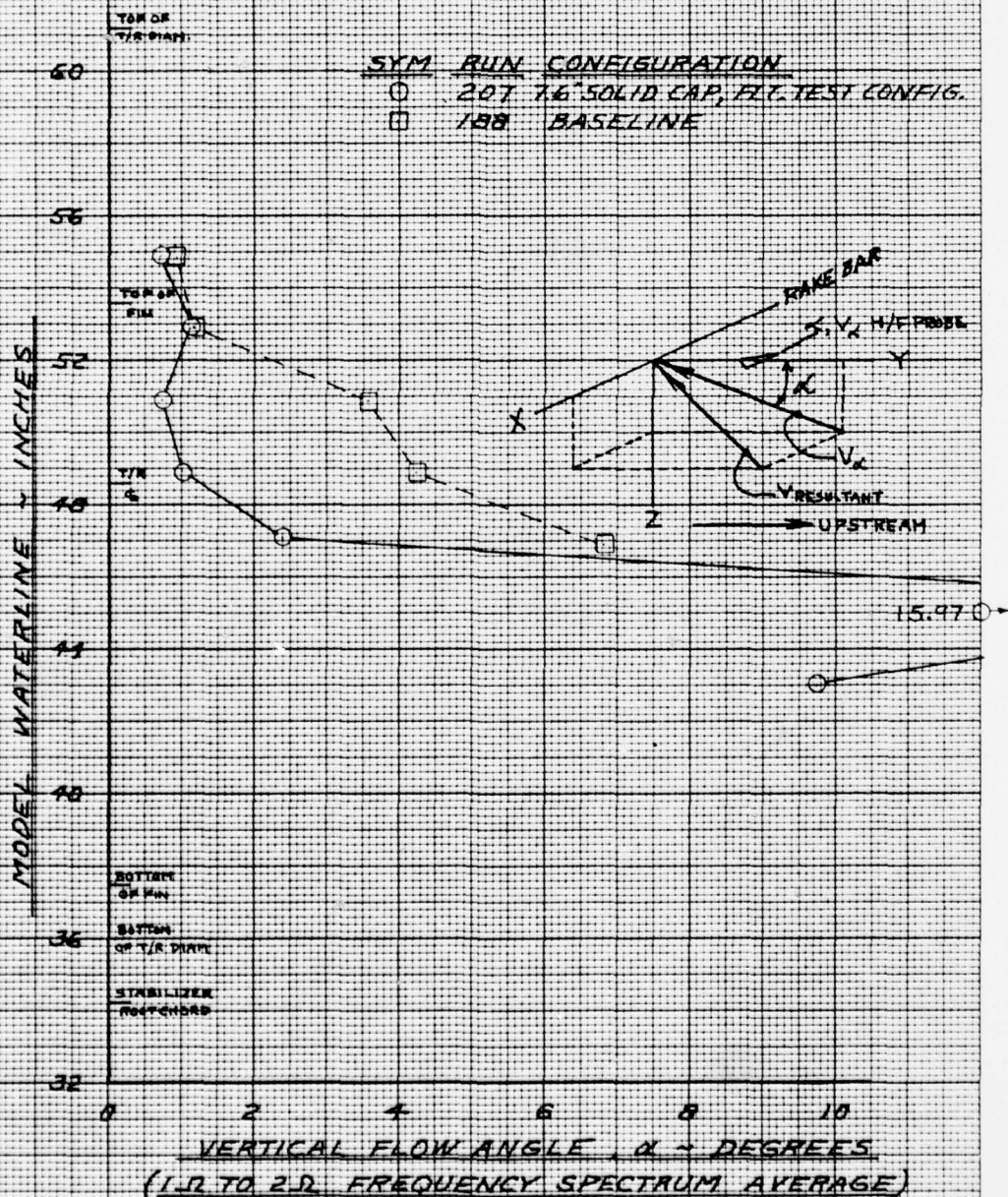


UNSTEADY WAKE X-Z VELOCITY COMPONENTS



ROTOR/HUB WAKE MODIFICATION STUDIES

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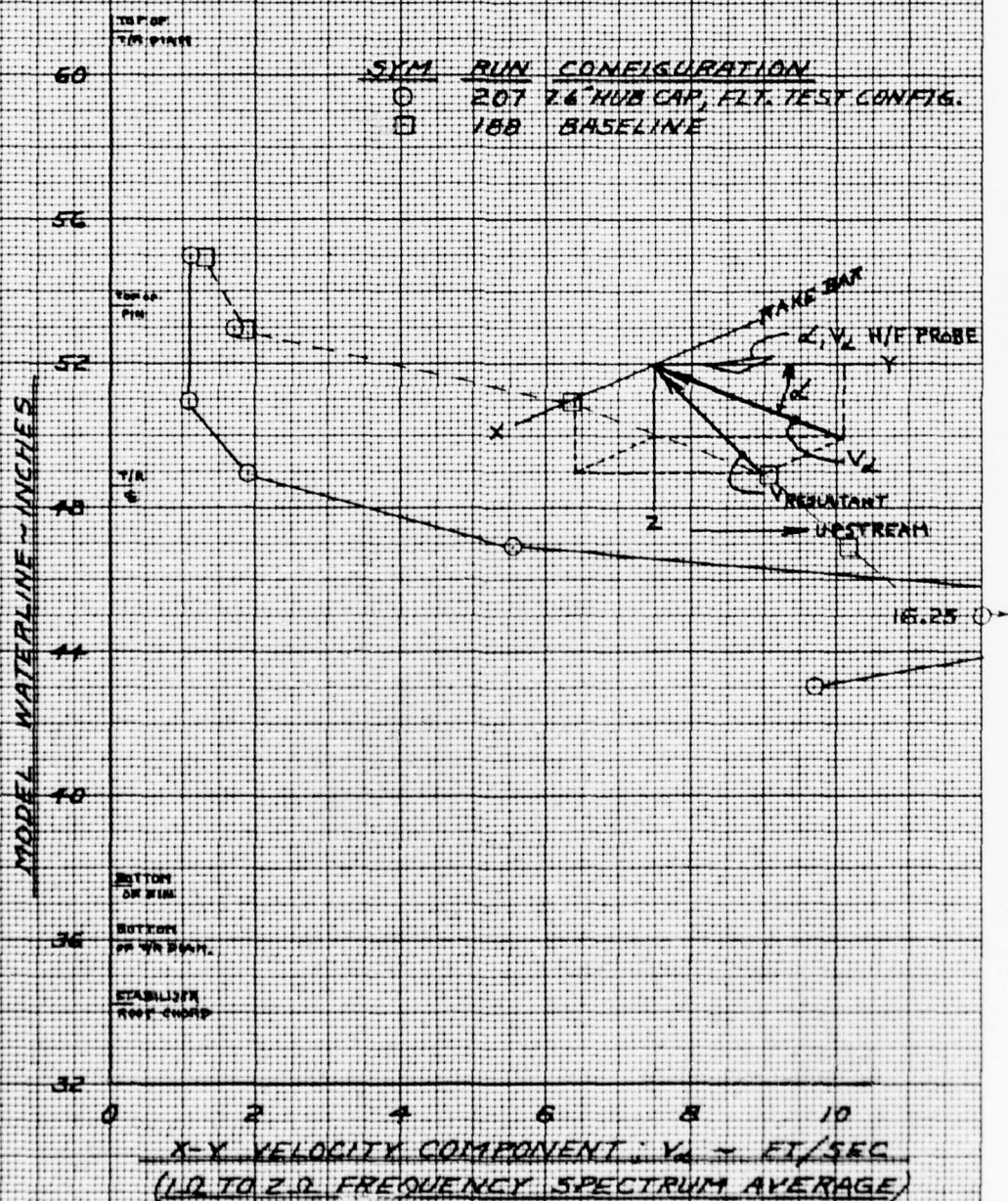


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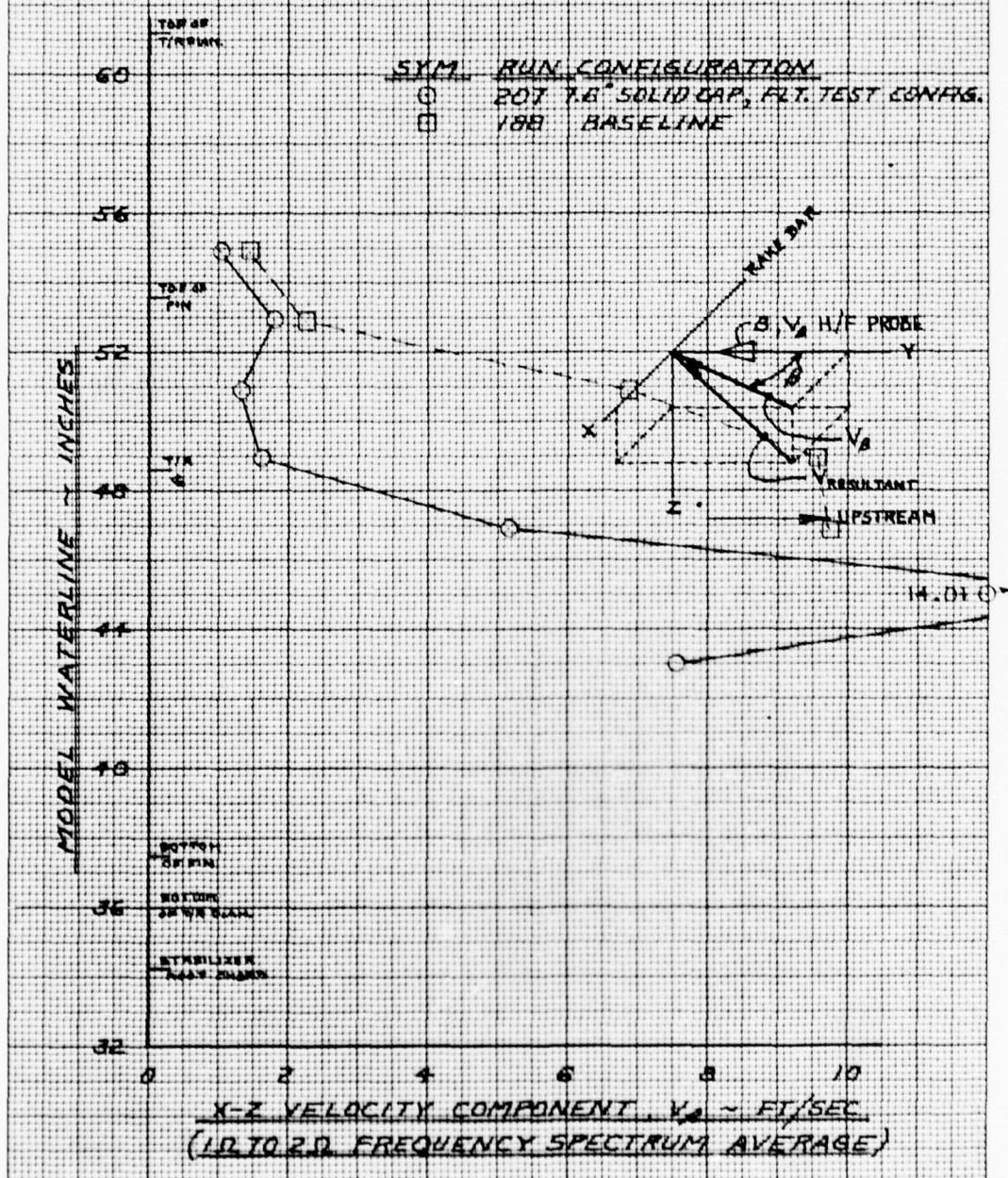
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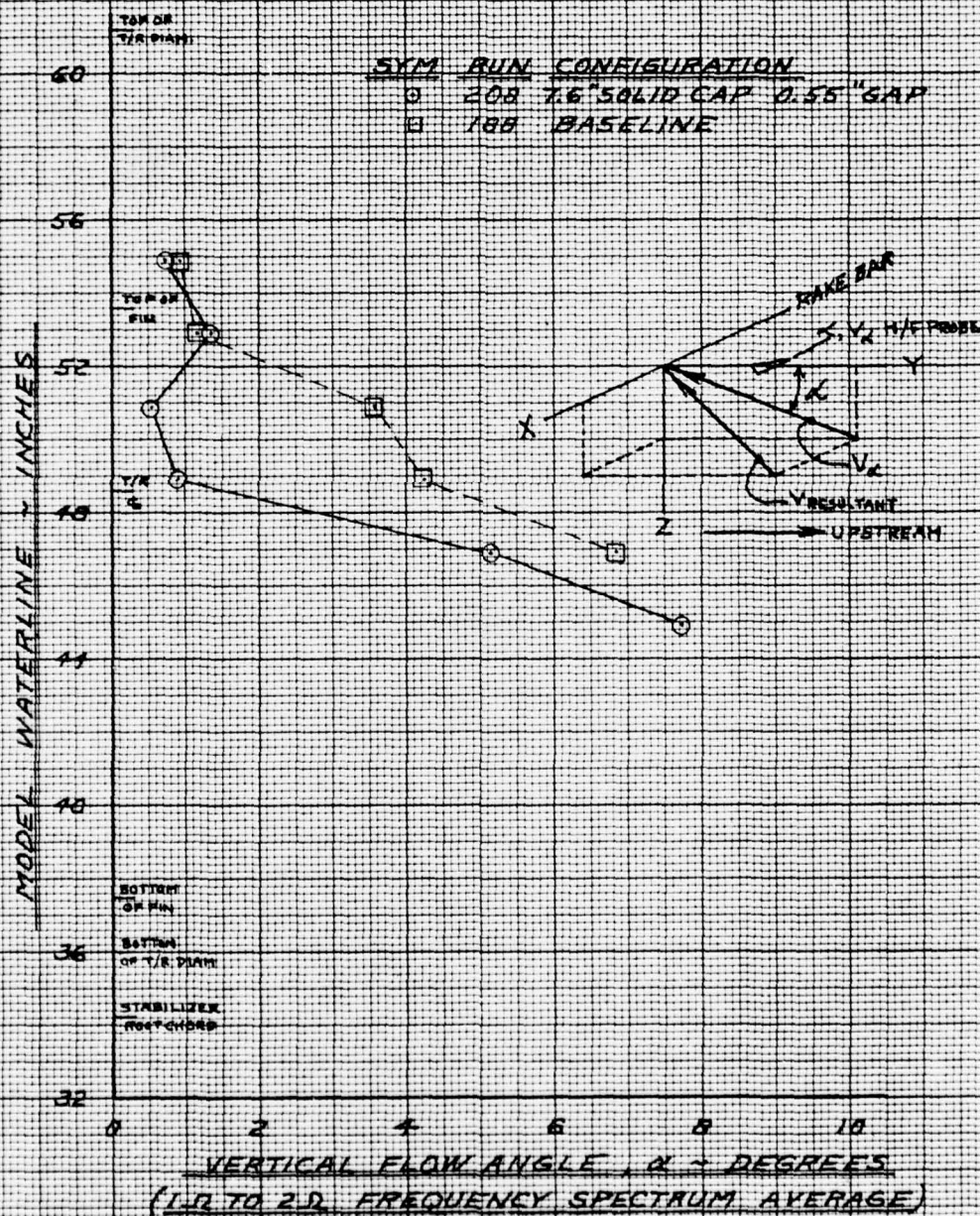
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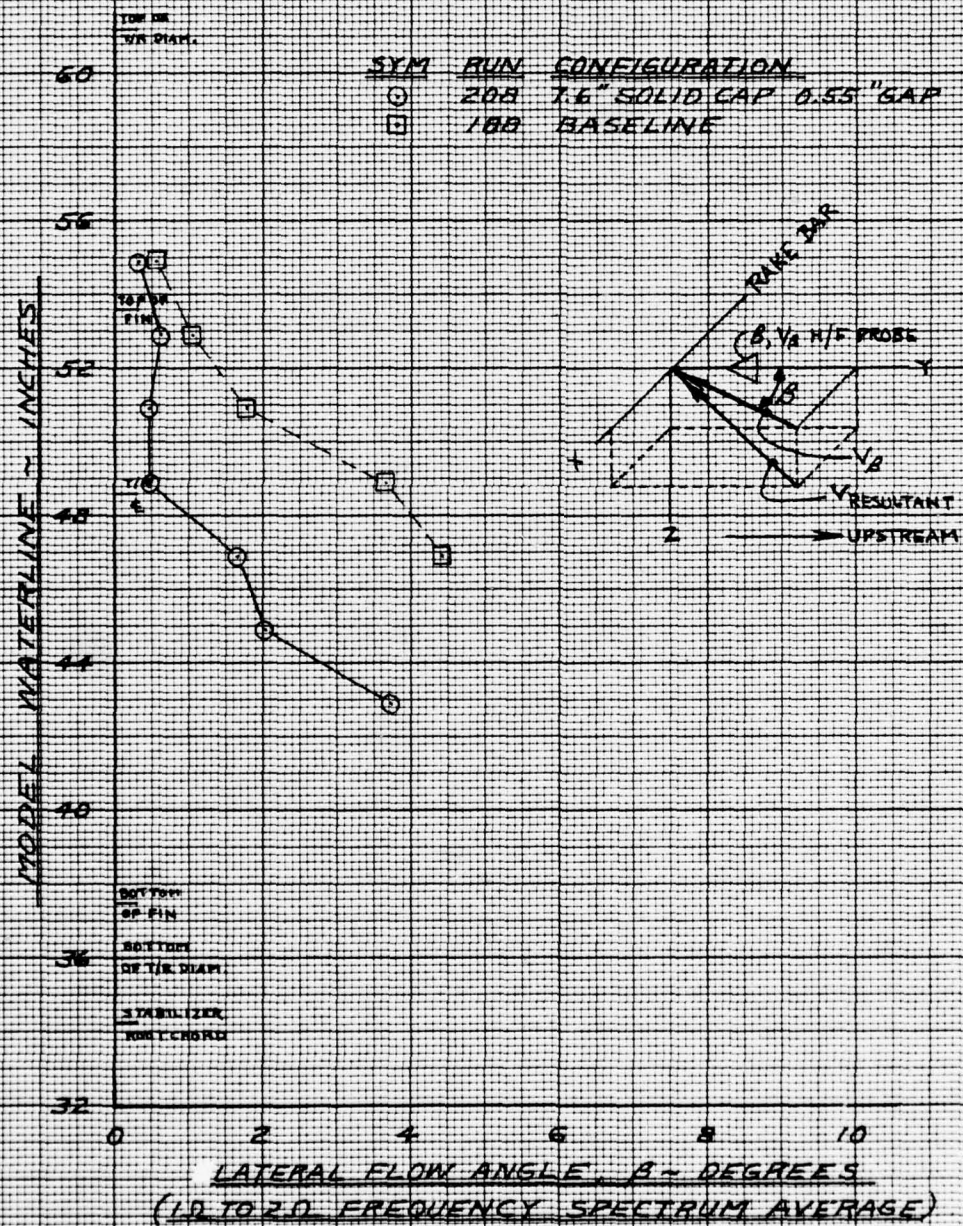
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UNSTEADY WAKE VERTICAL FLOW ANGLES



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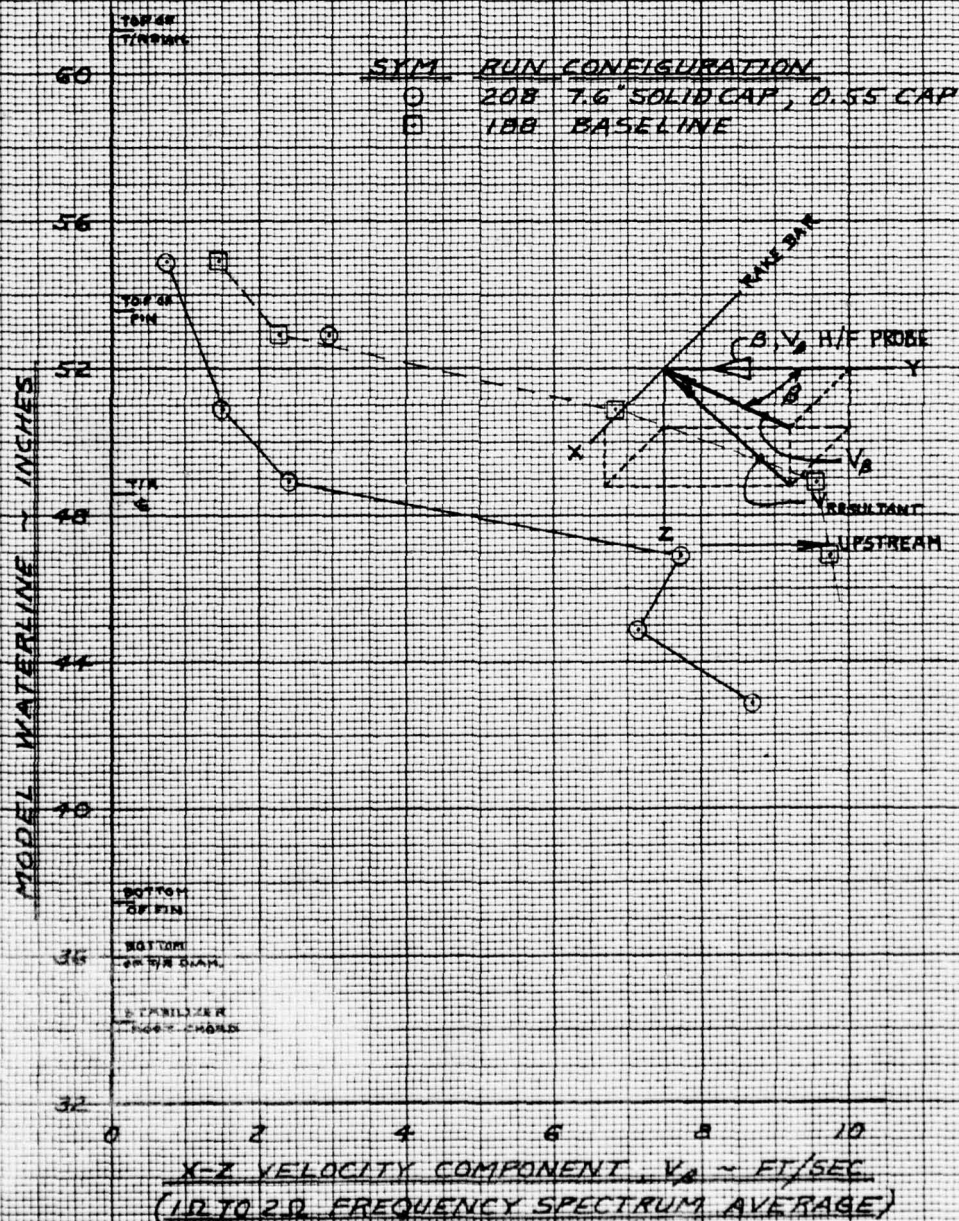


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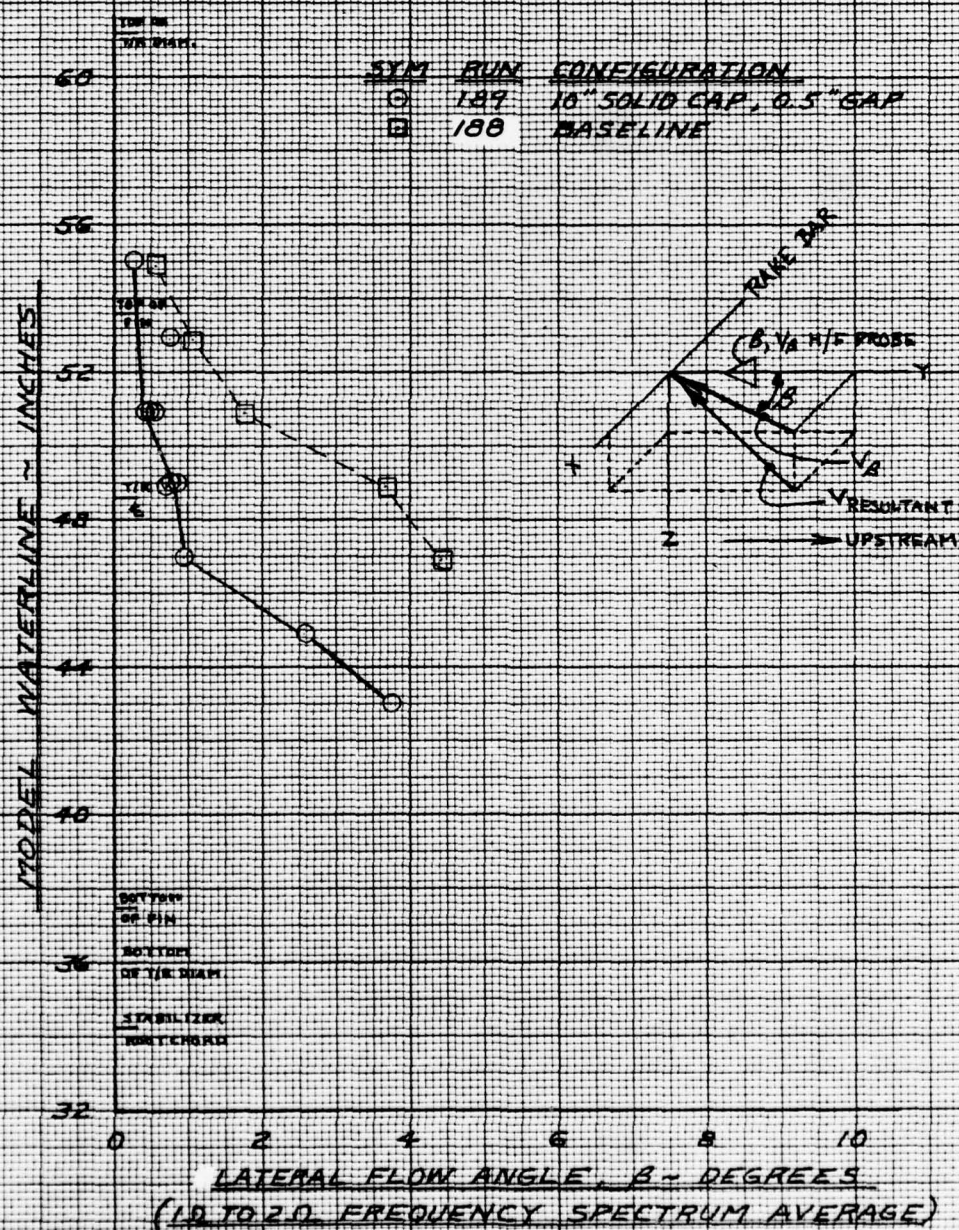


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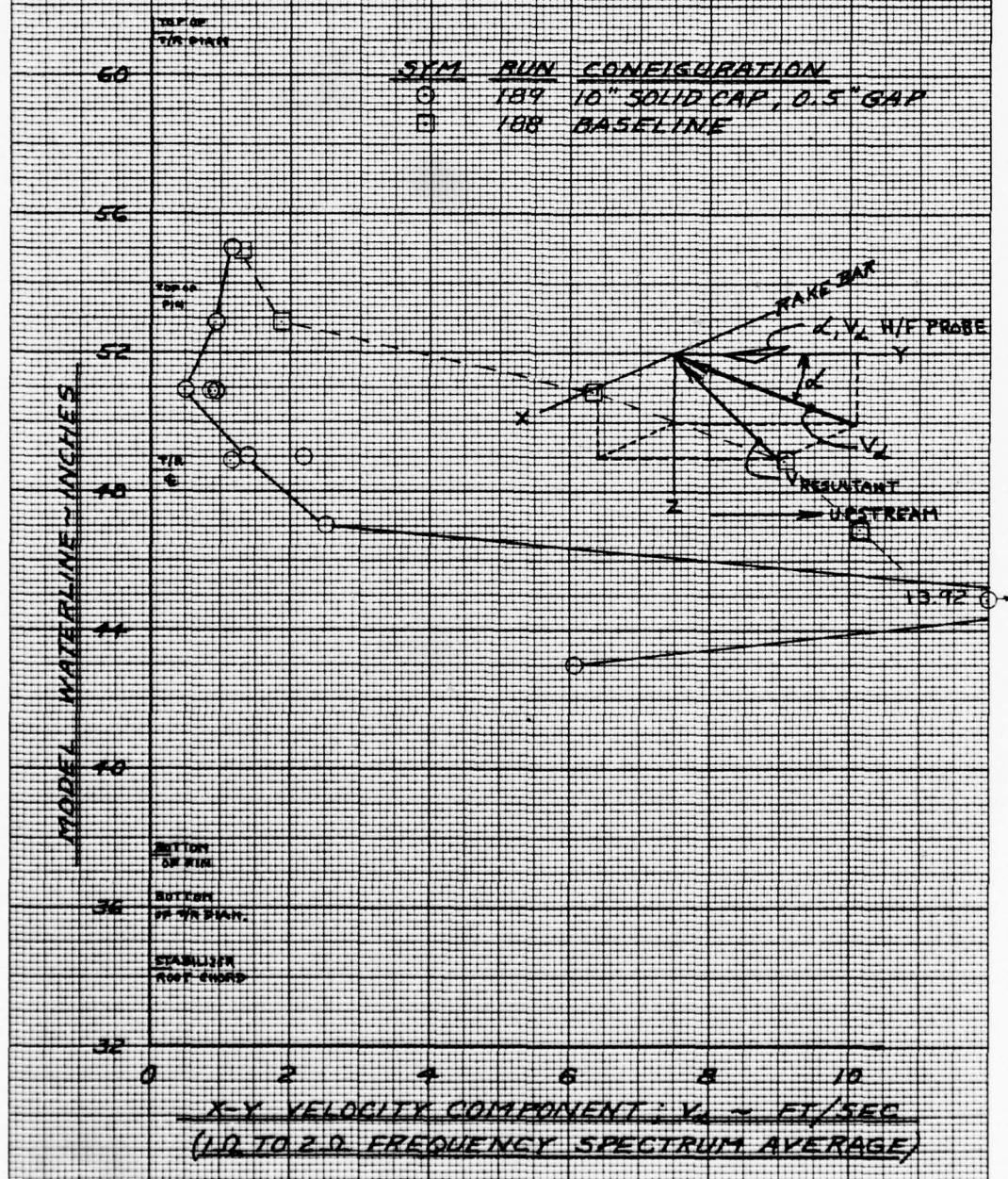
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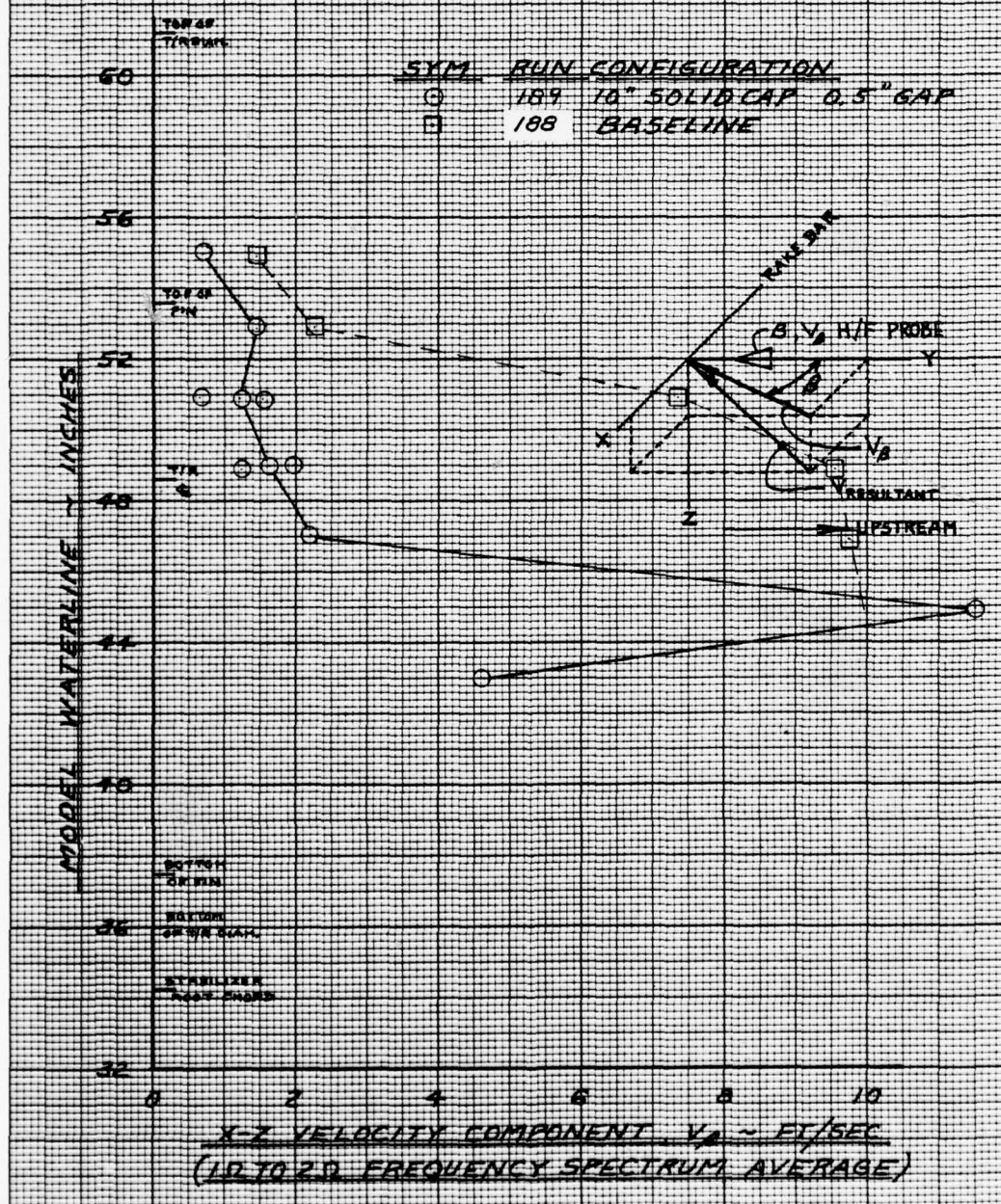
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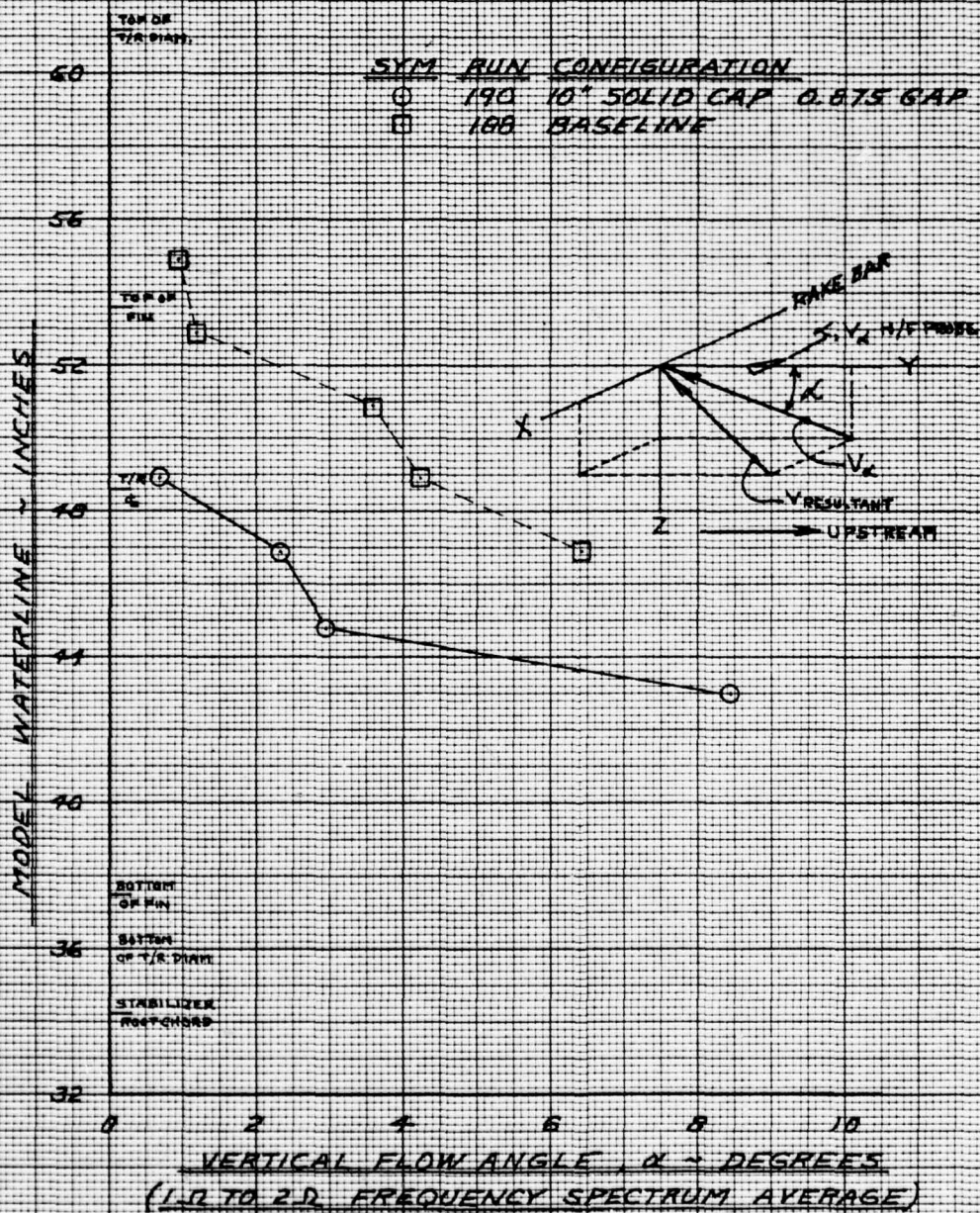
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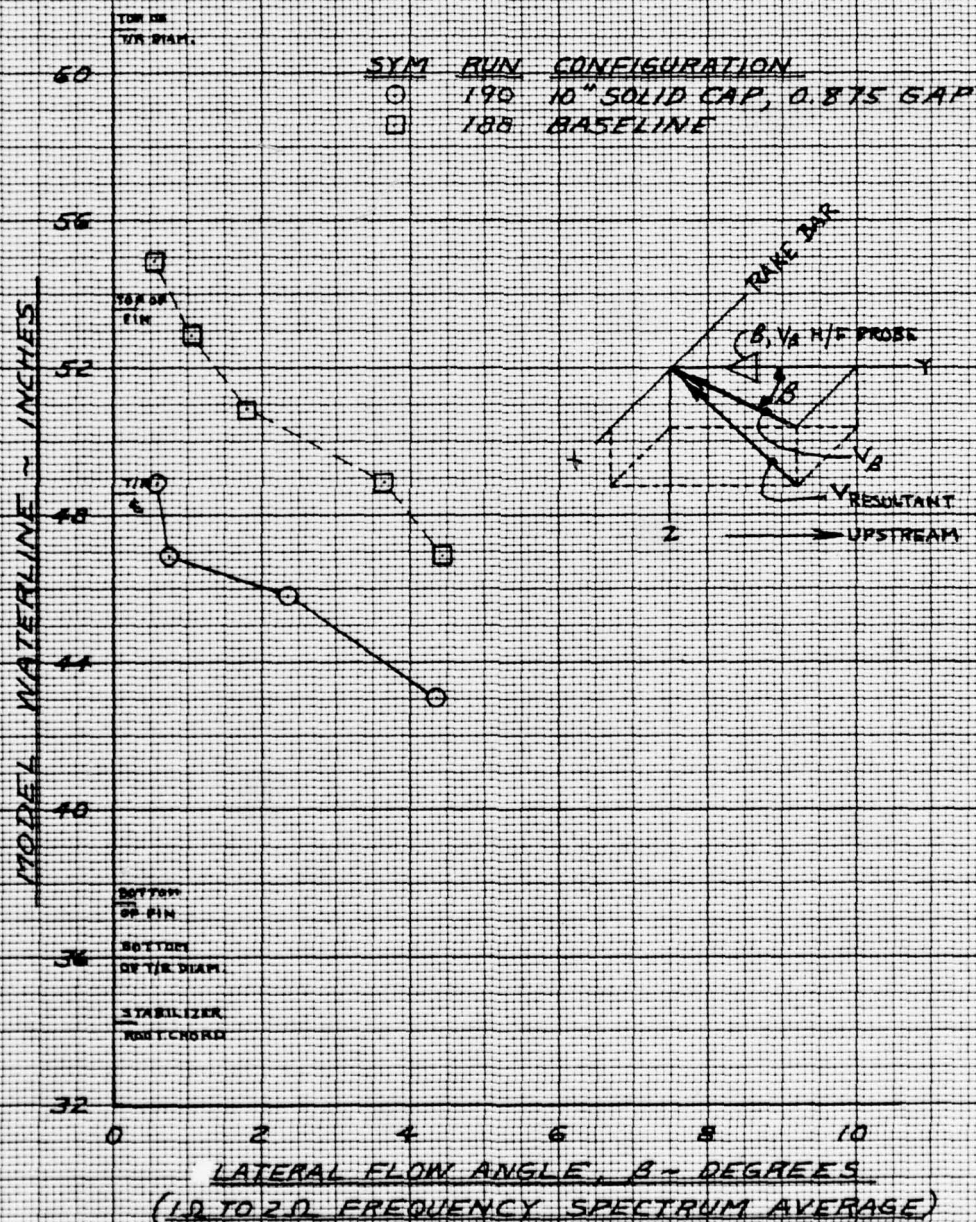
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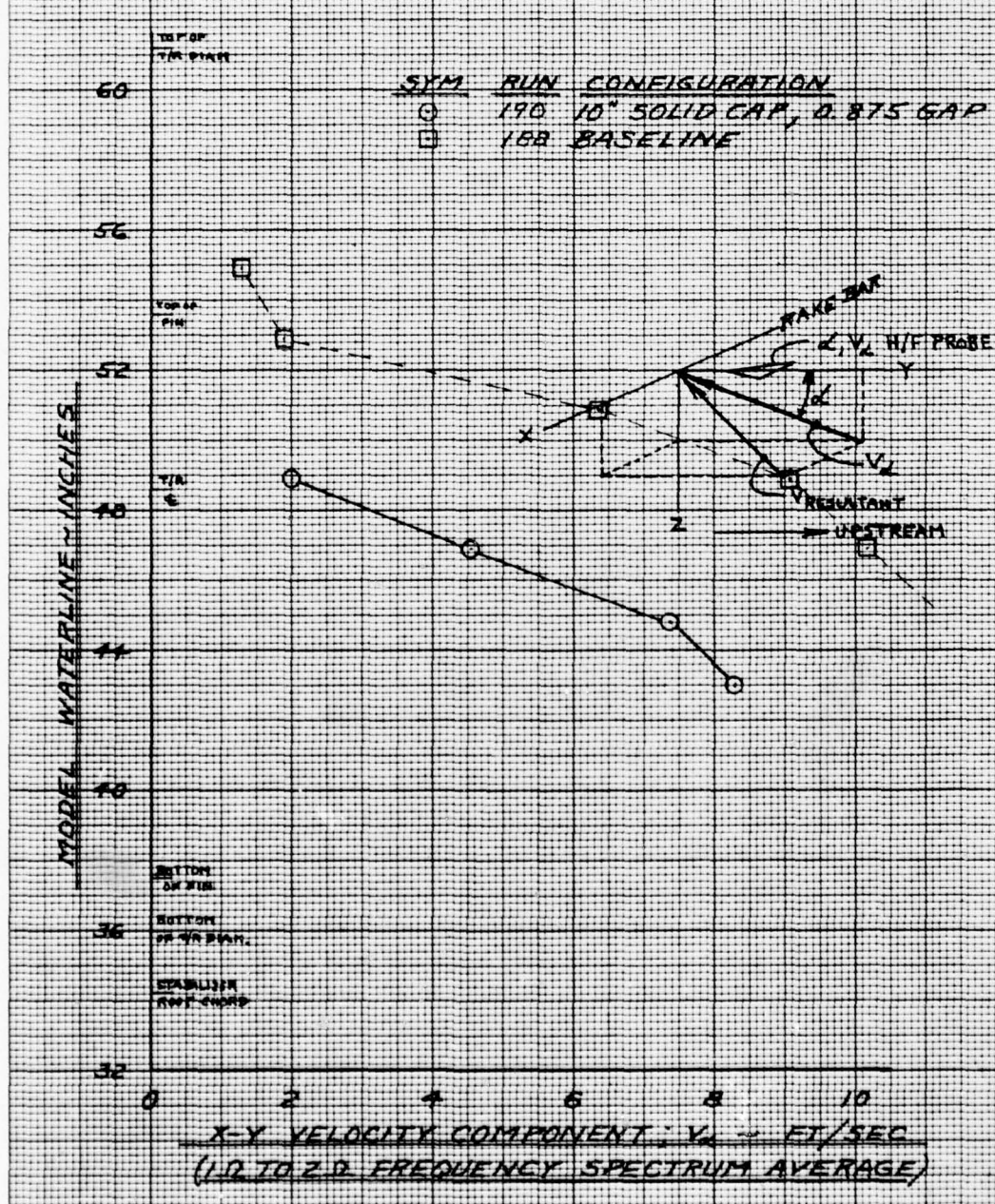
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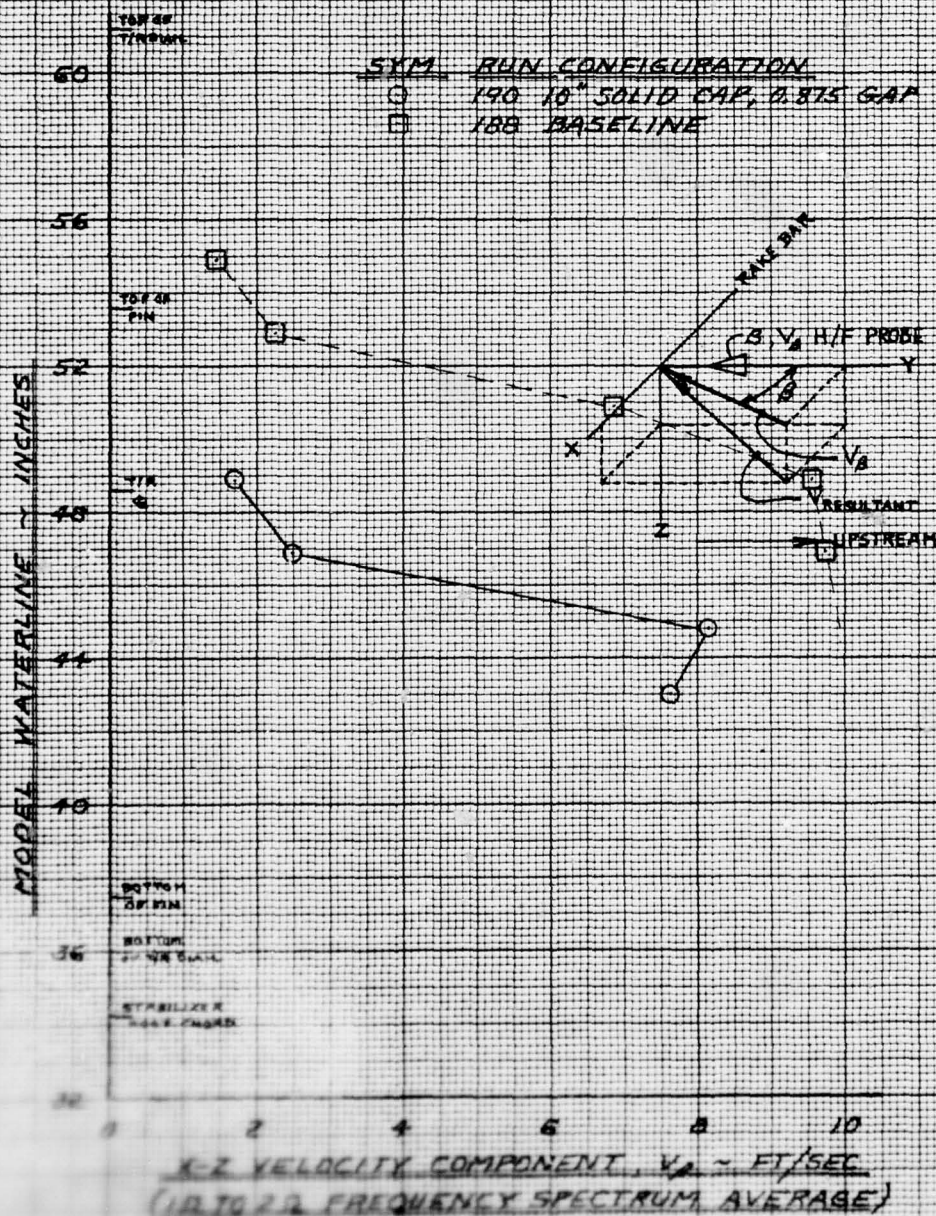
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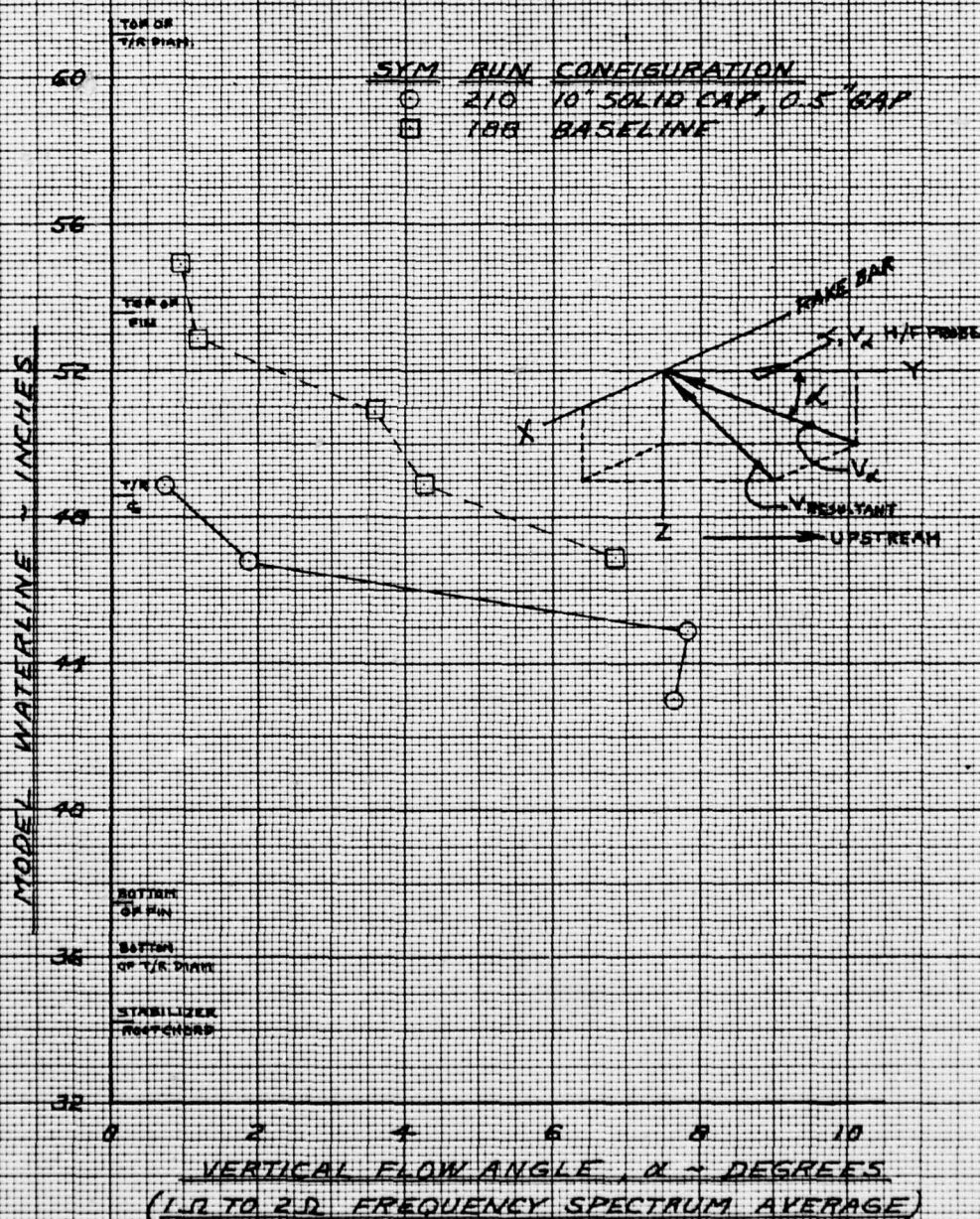
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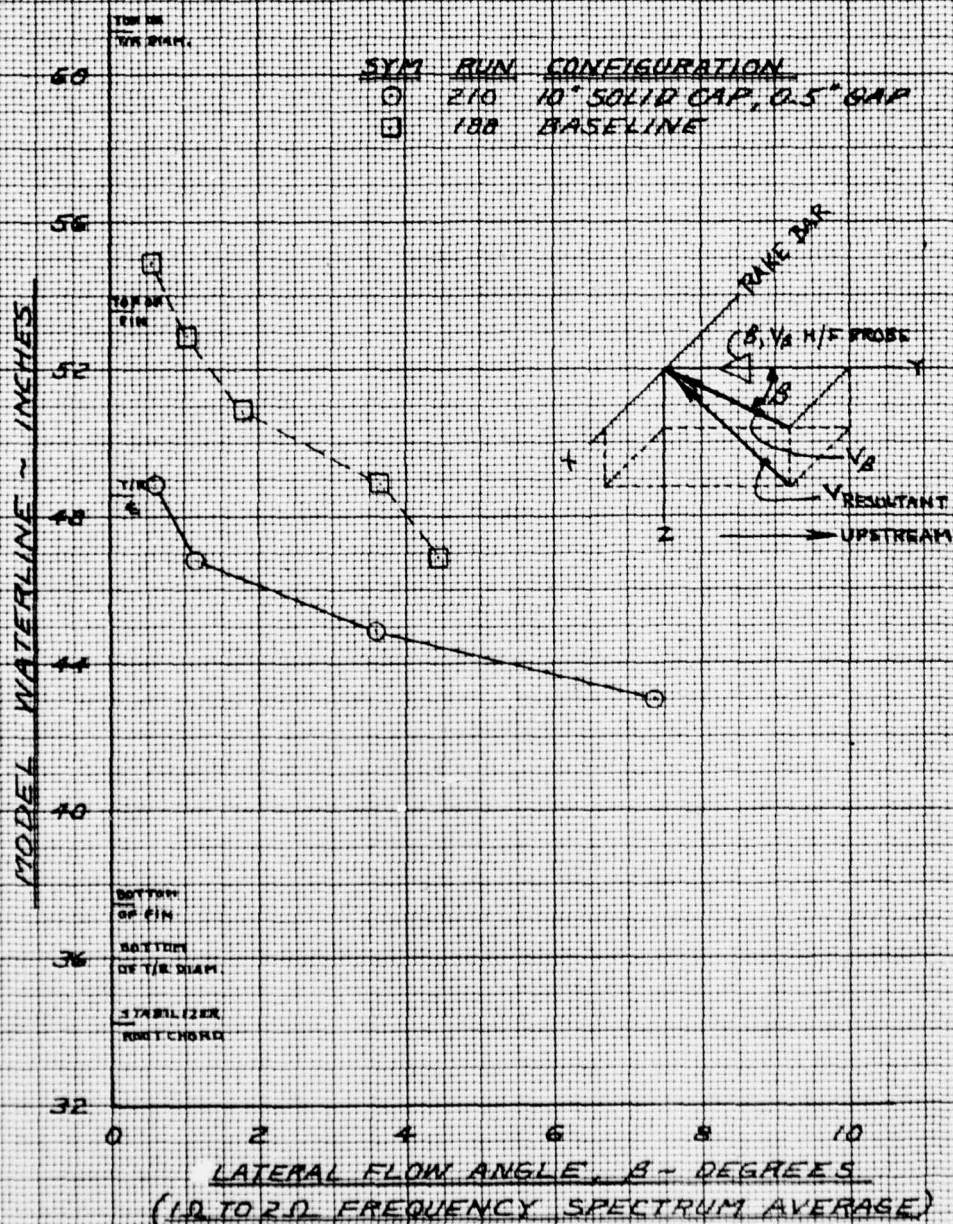
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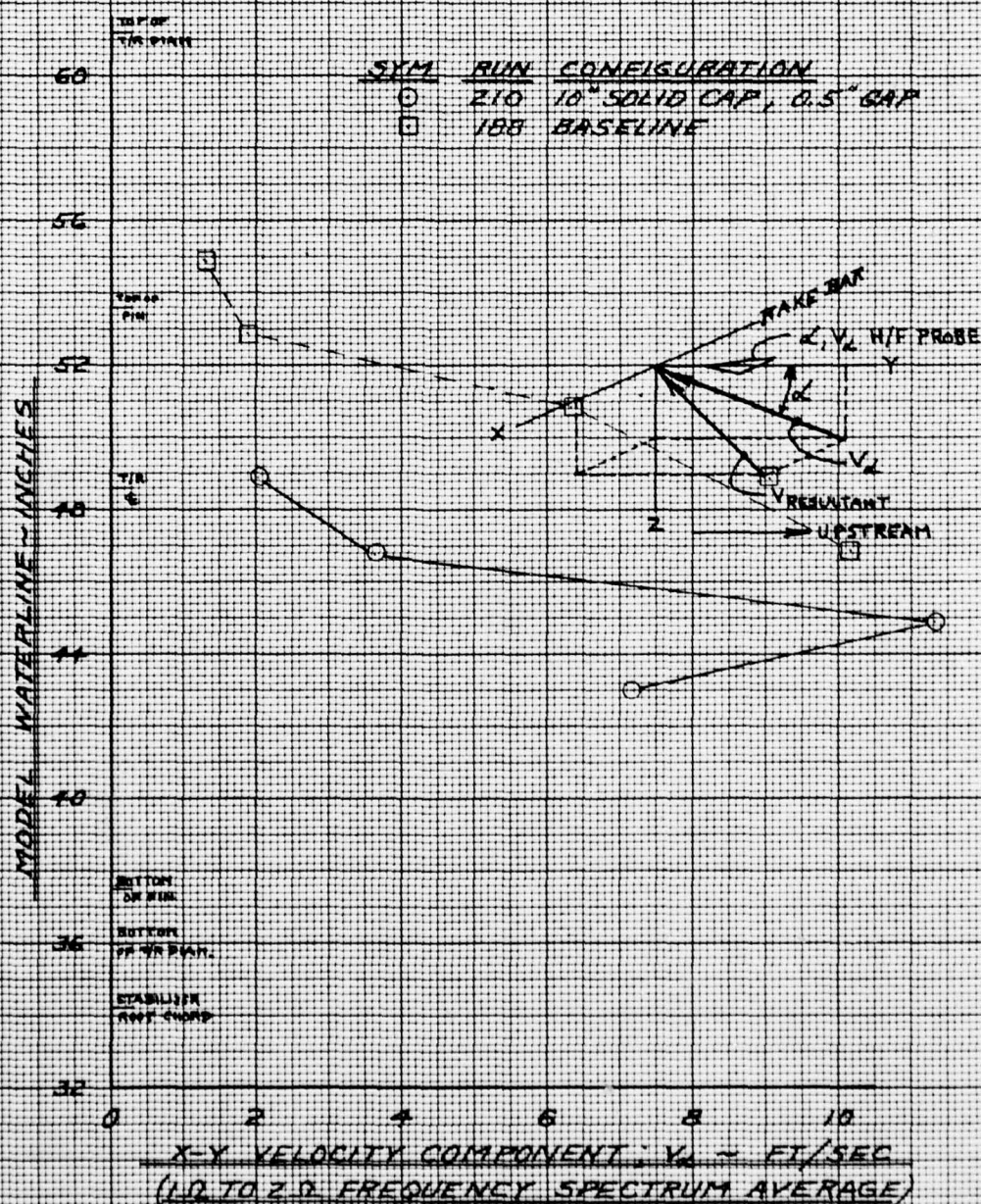
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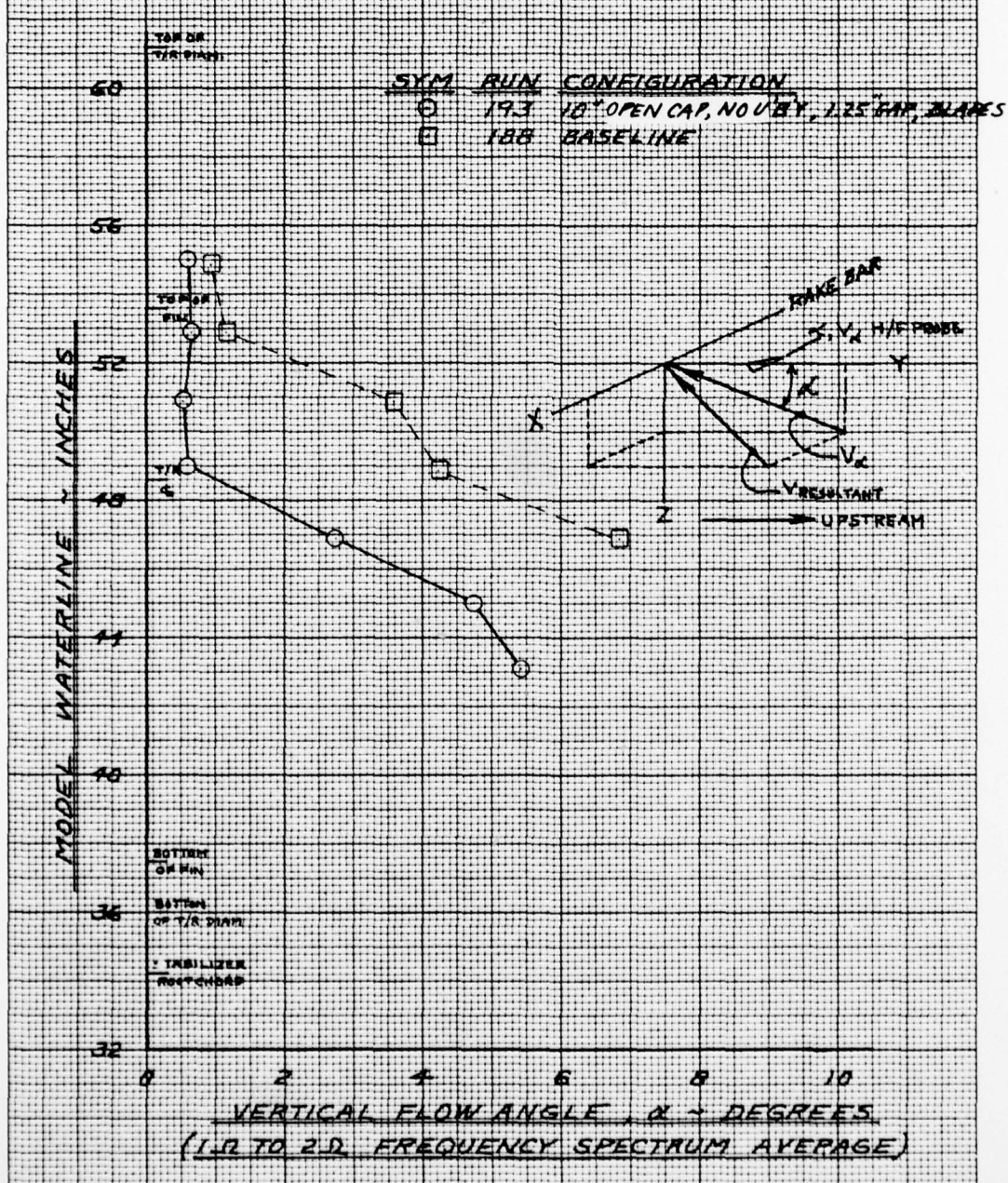


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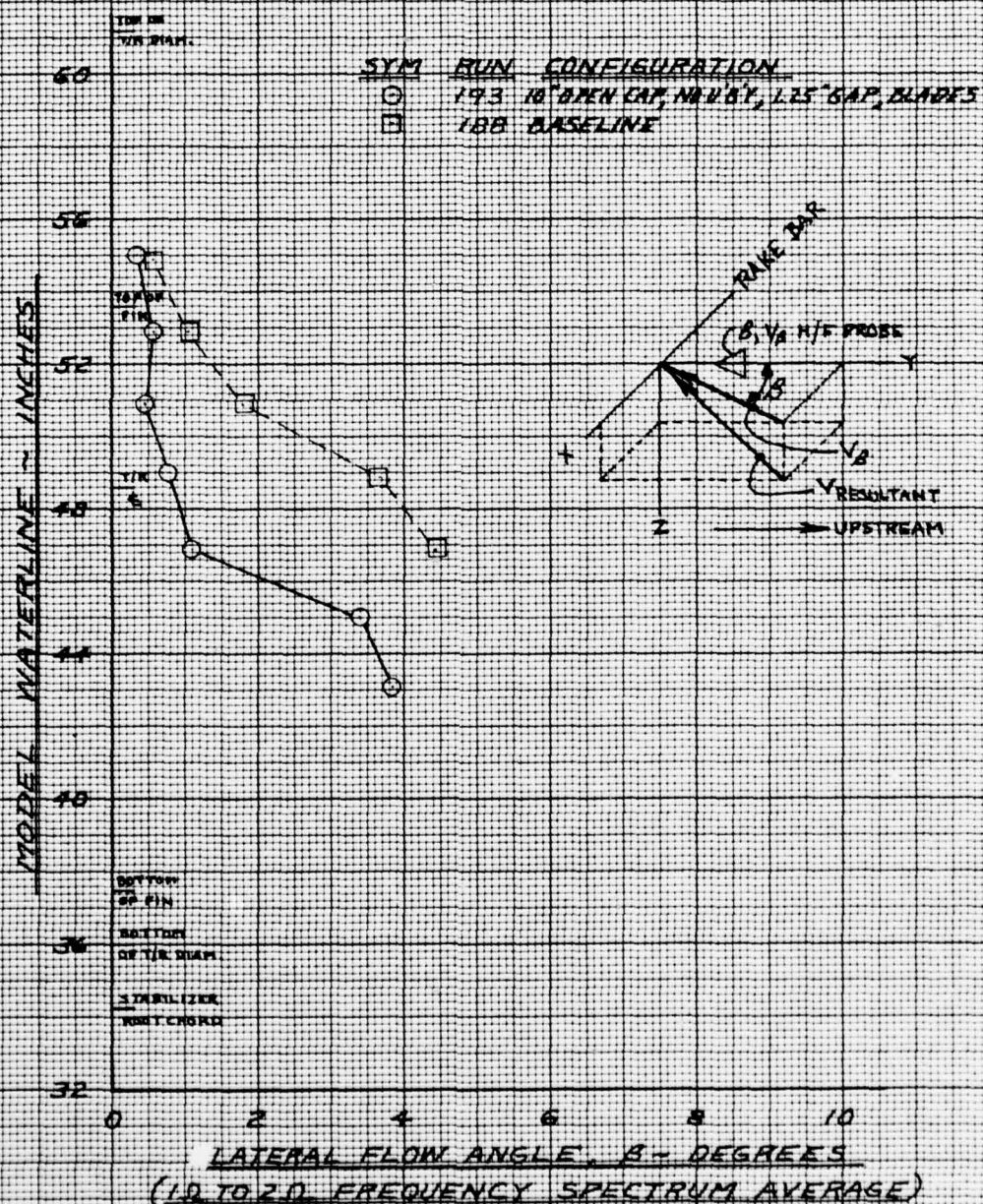
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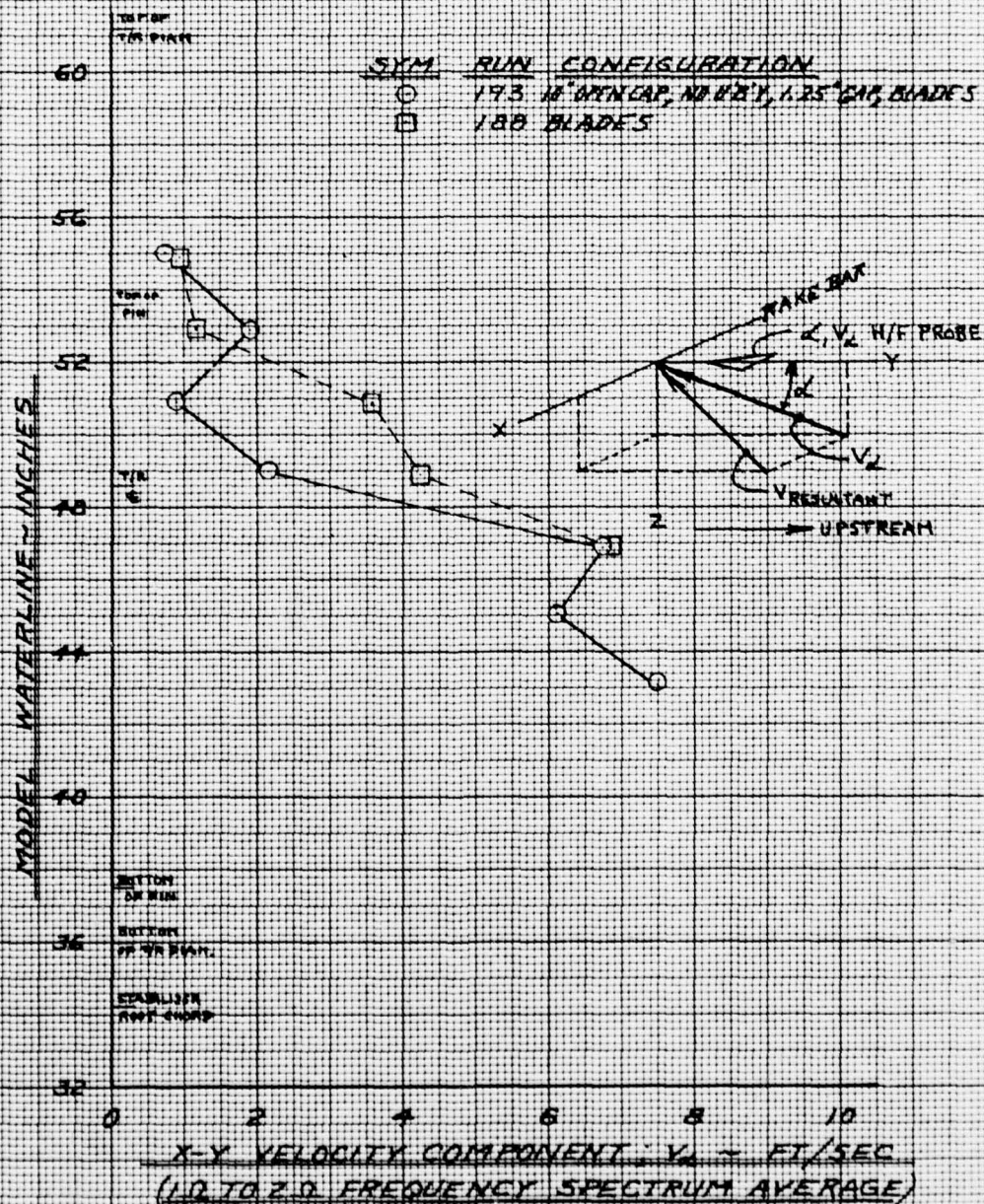
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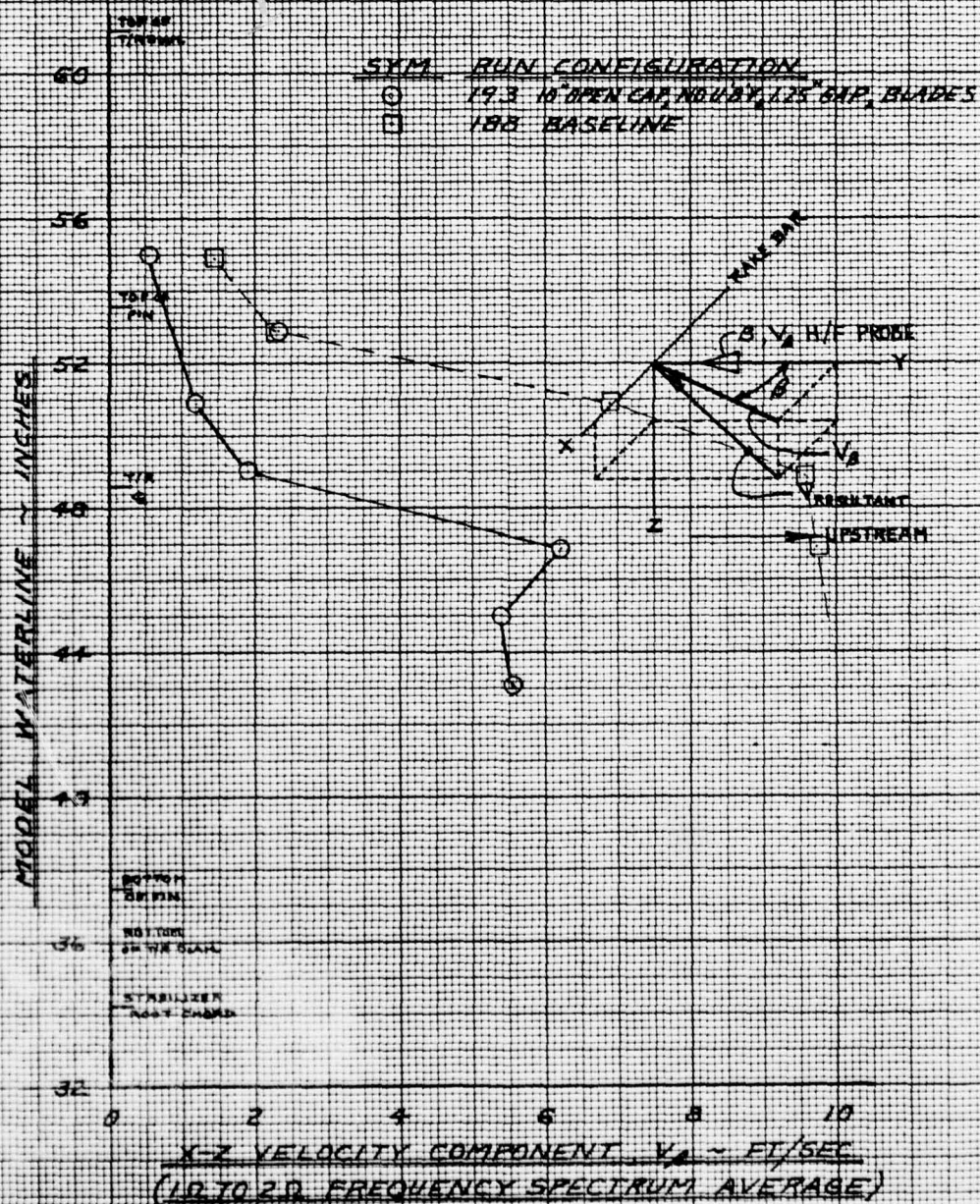
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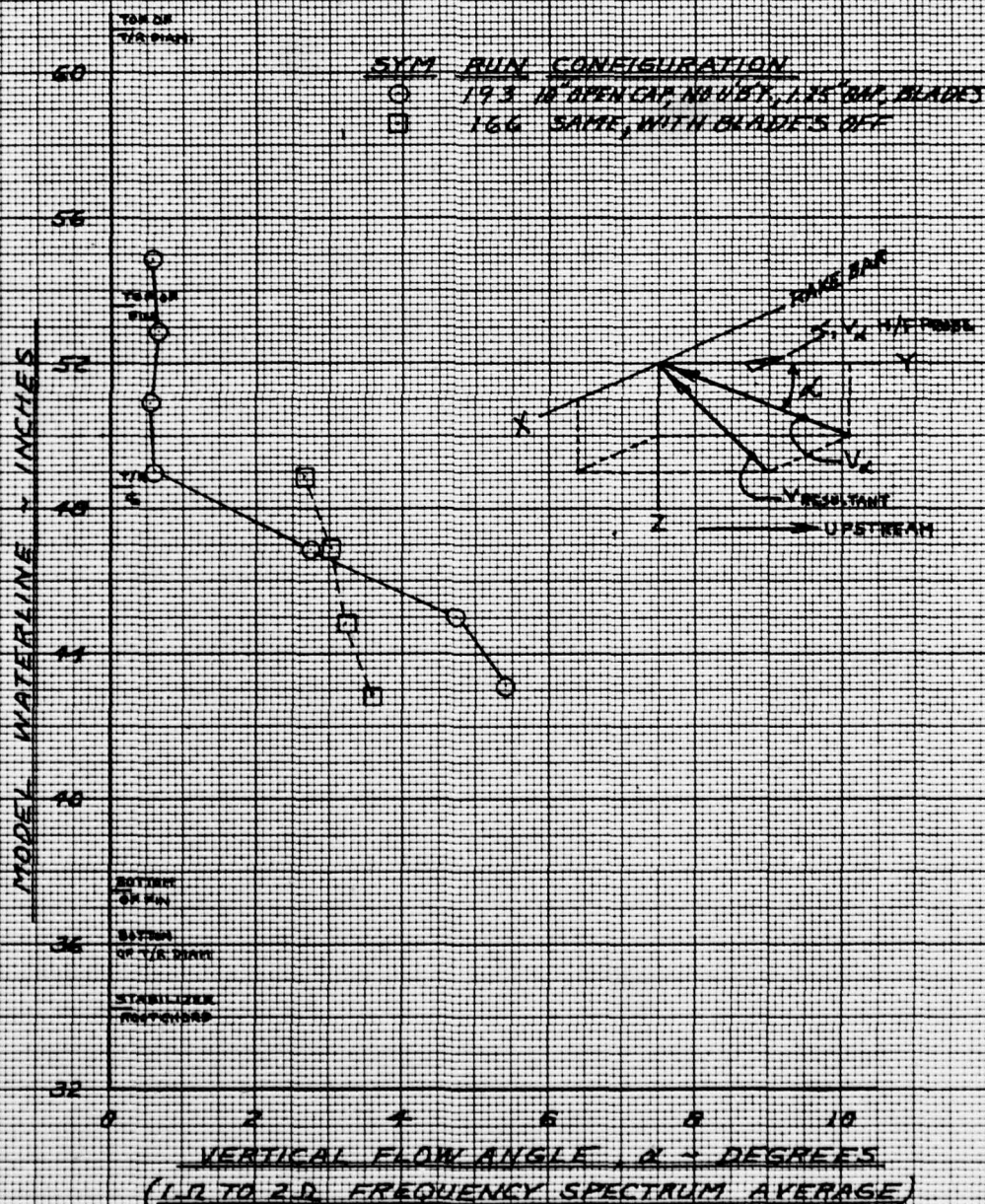
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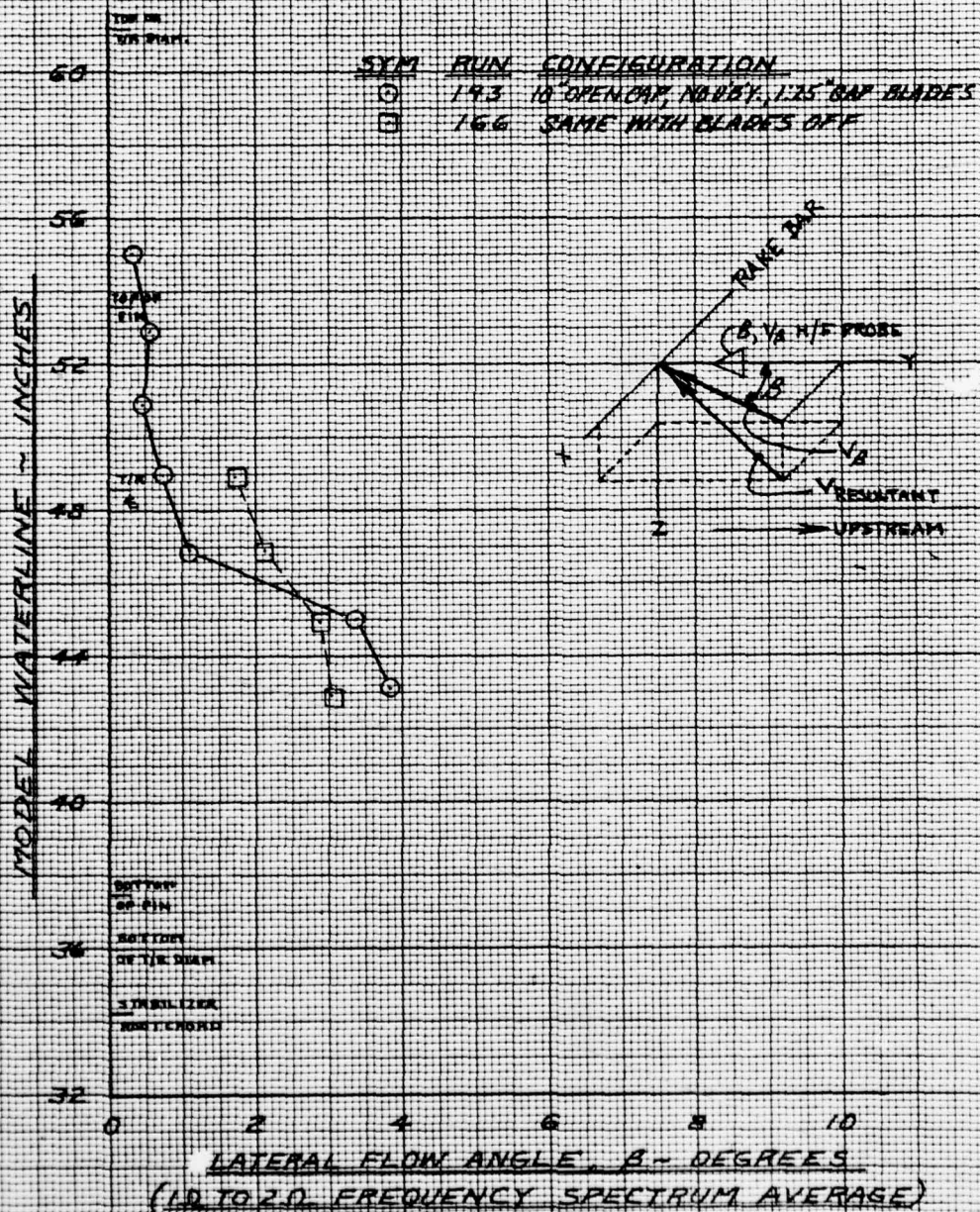
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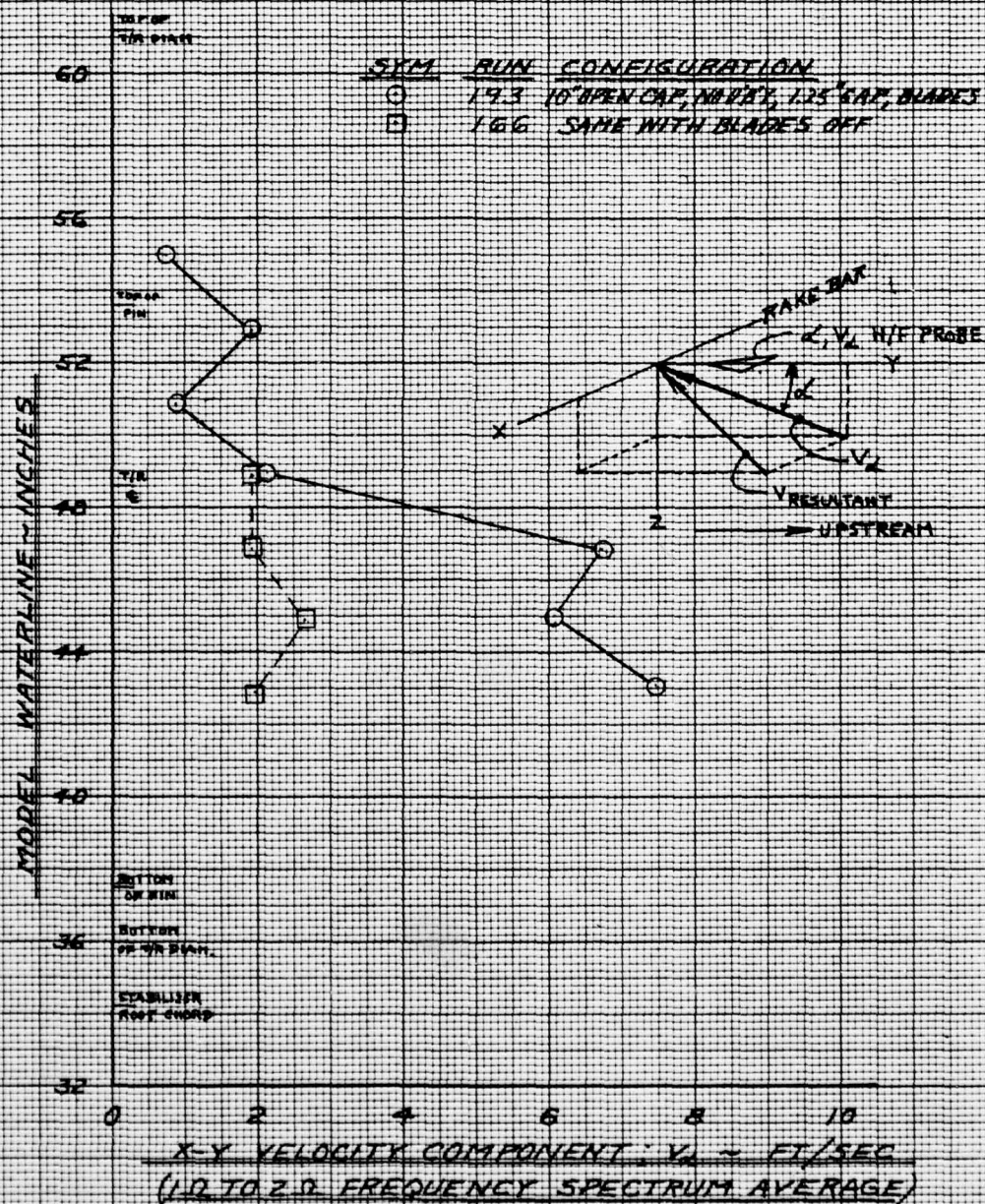
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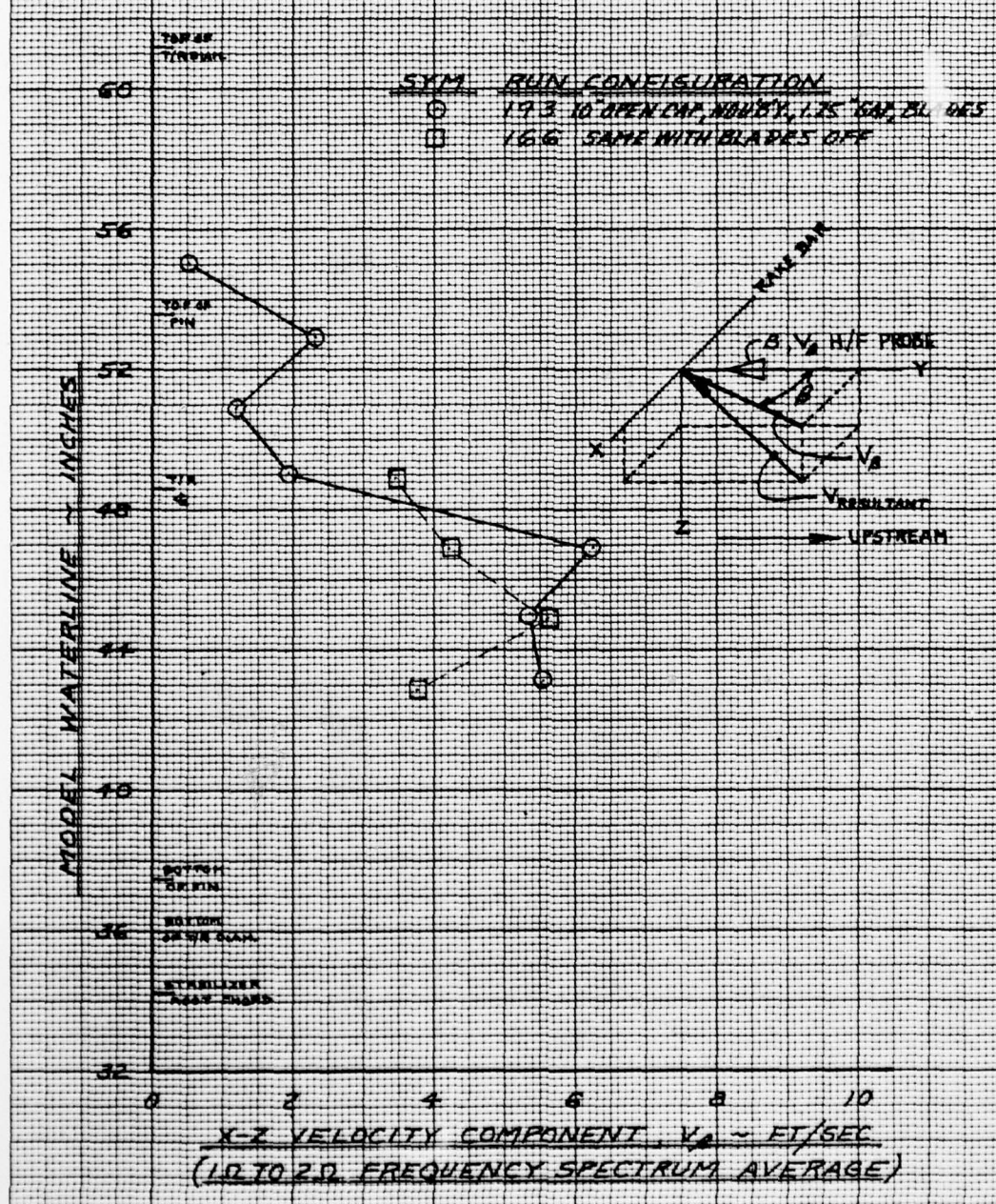
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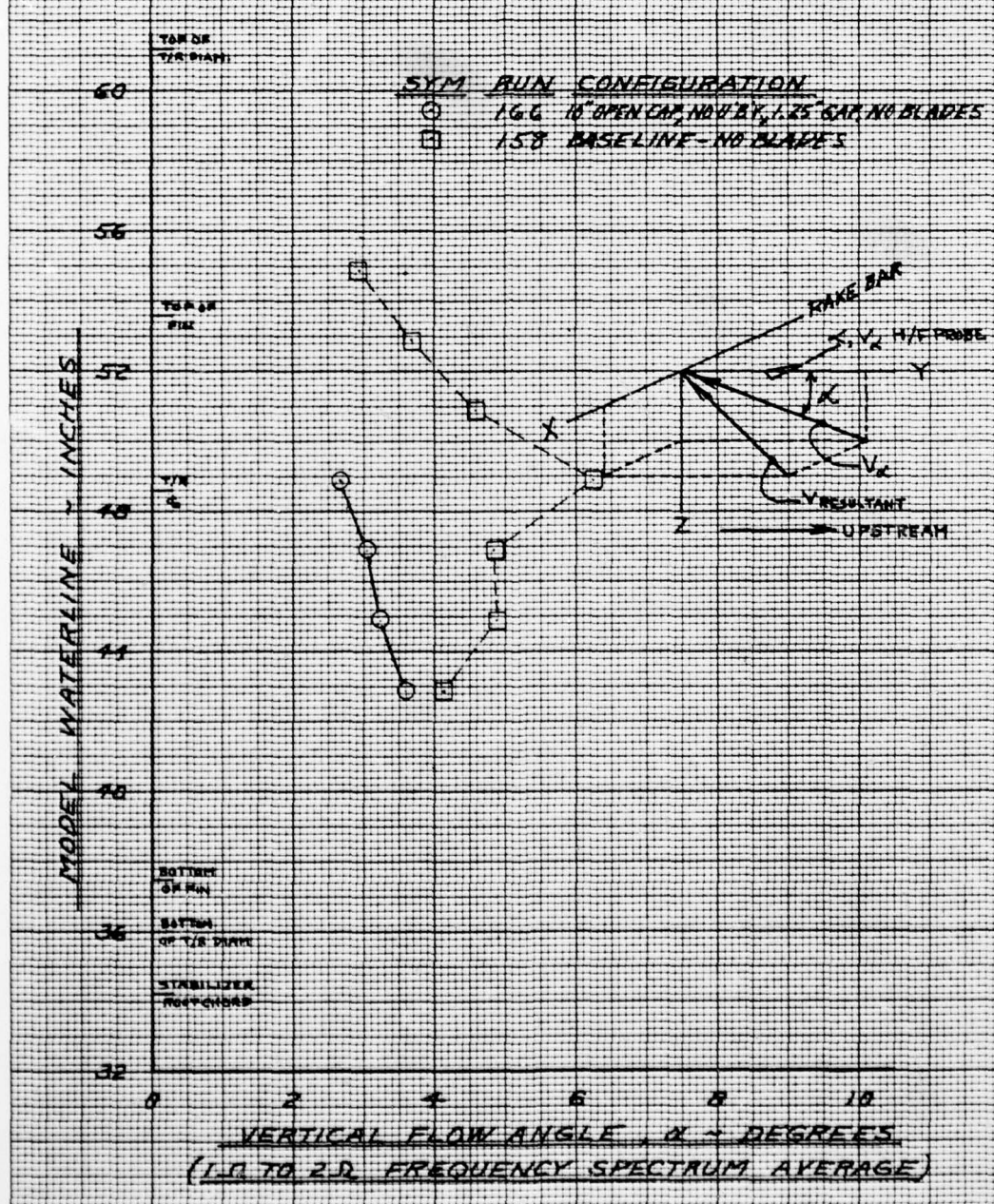
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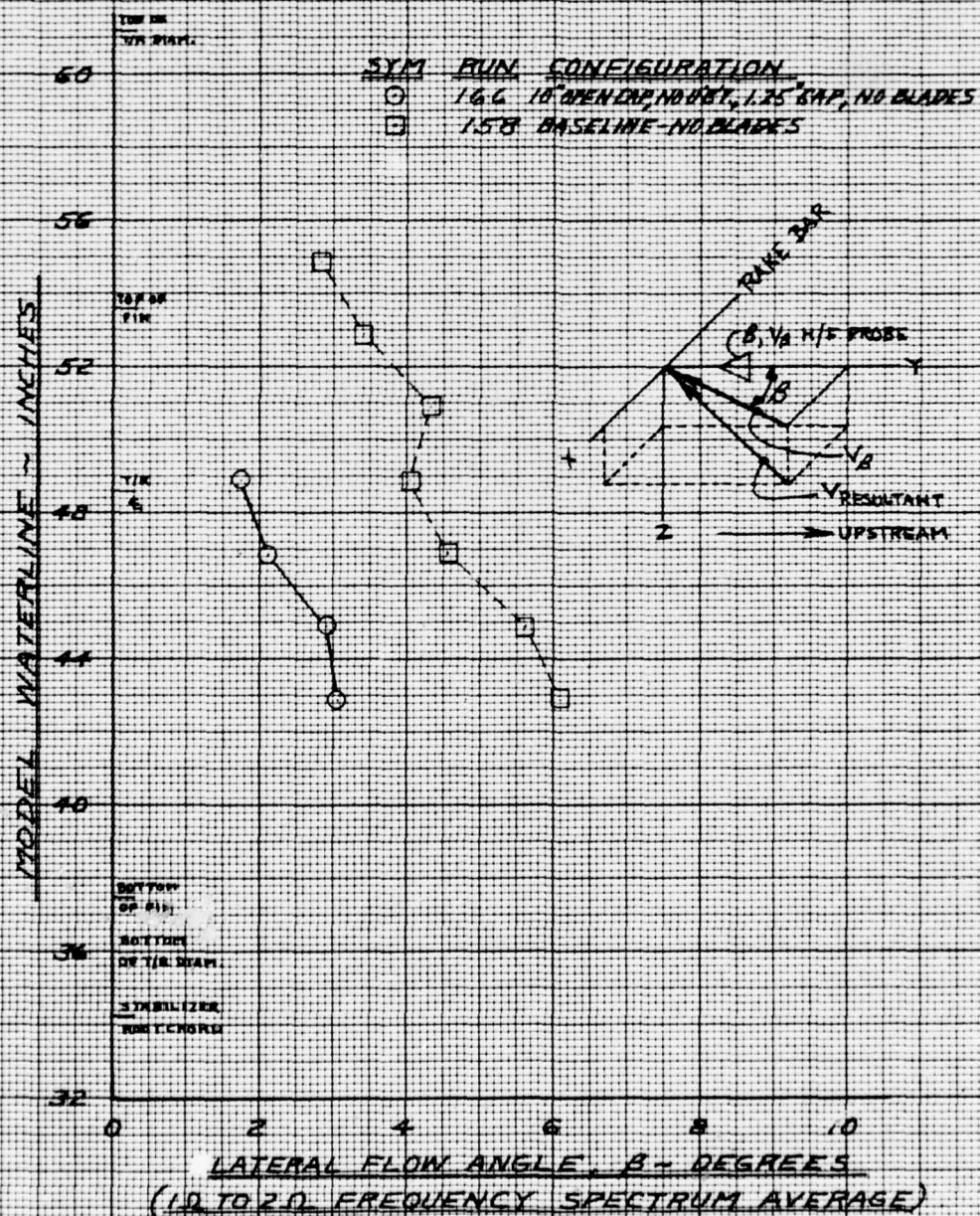


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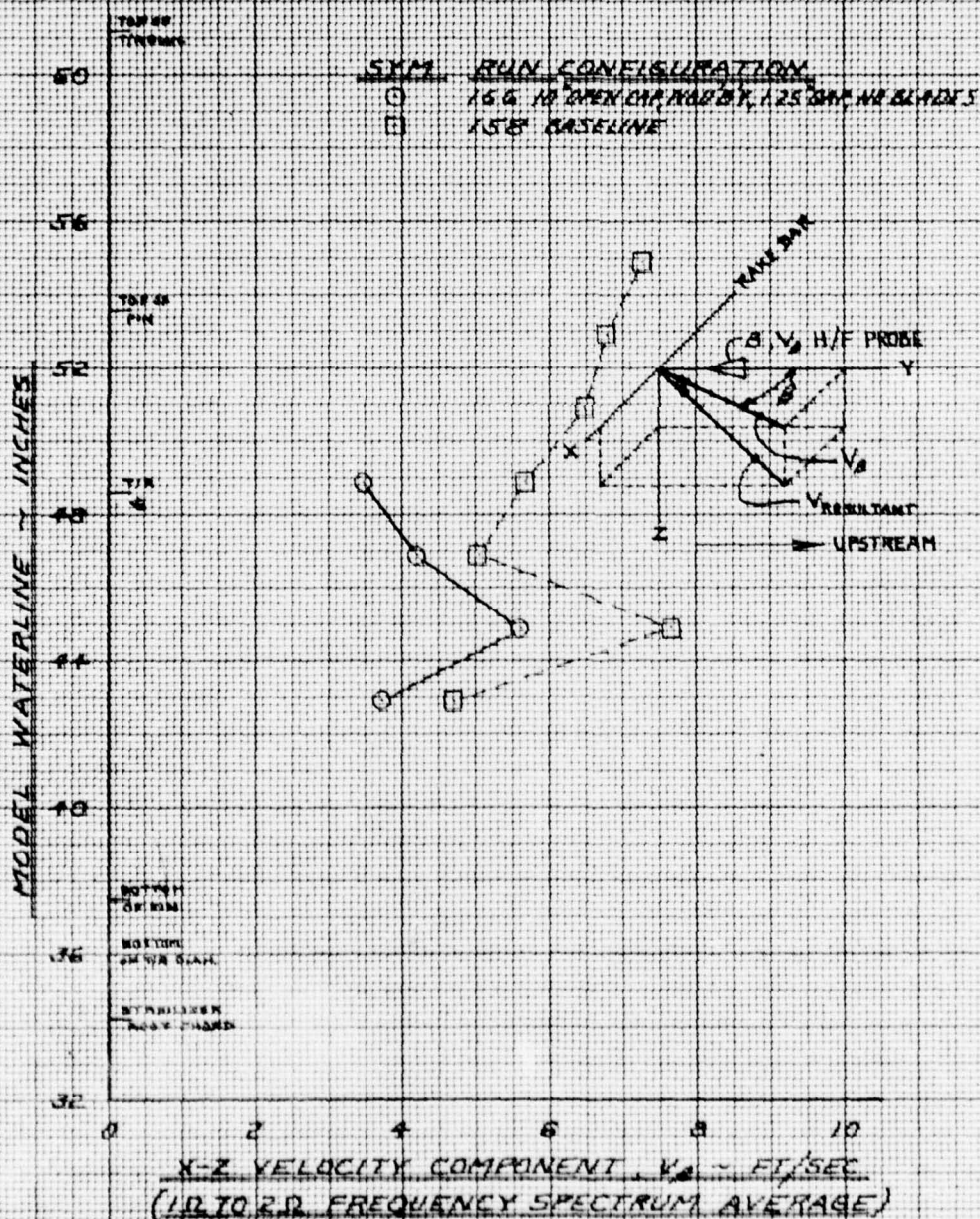


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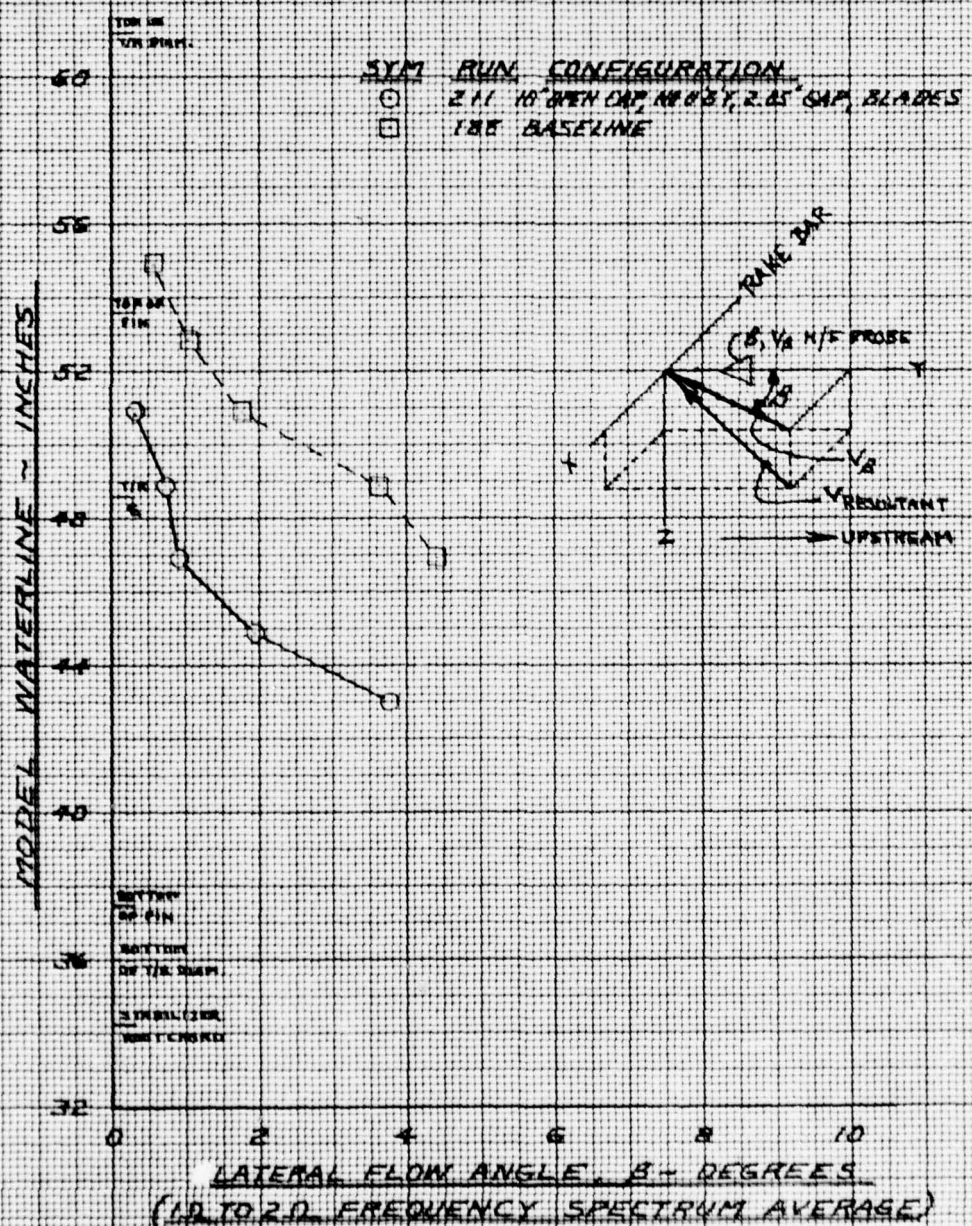


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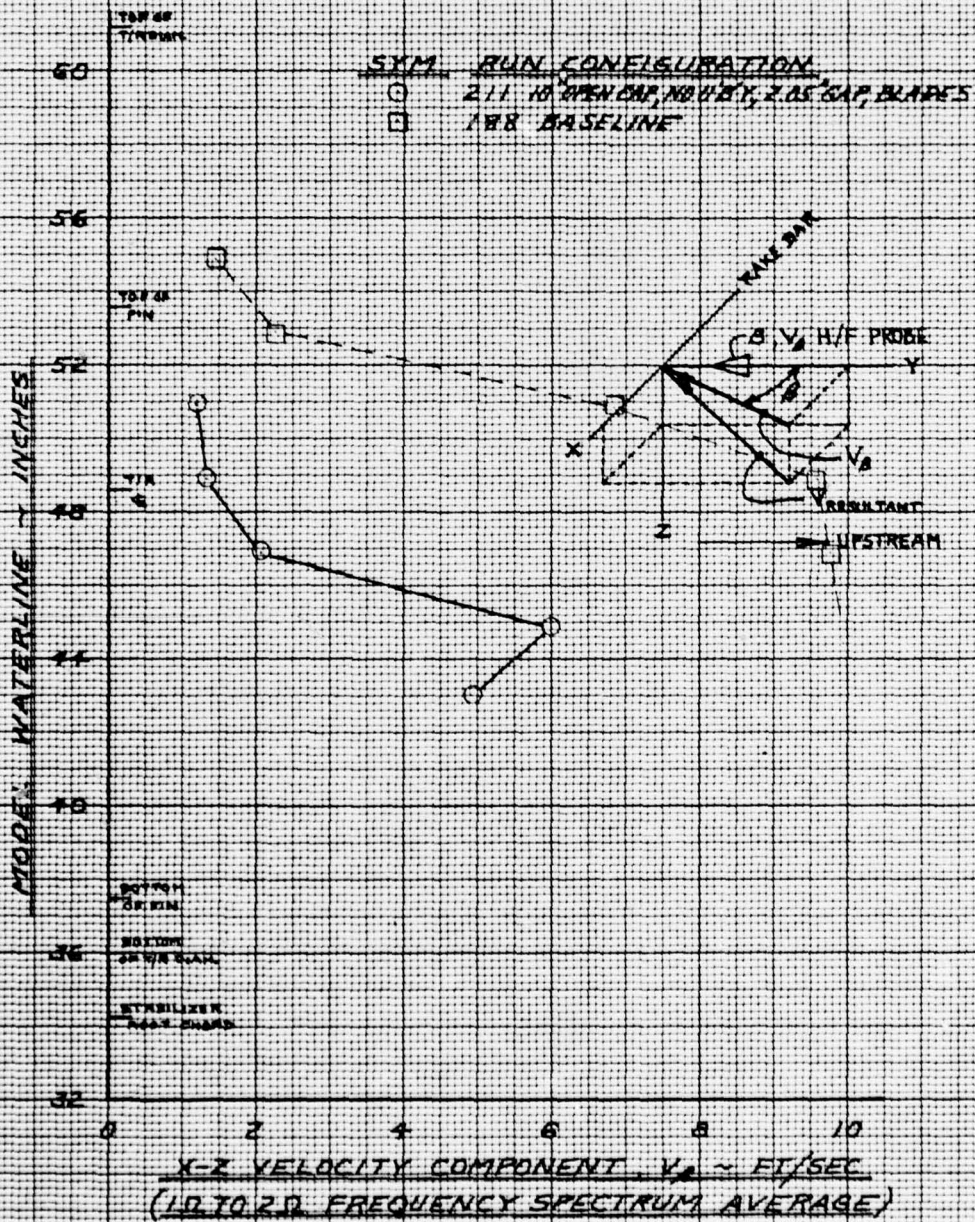


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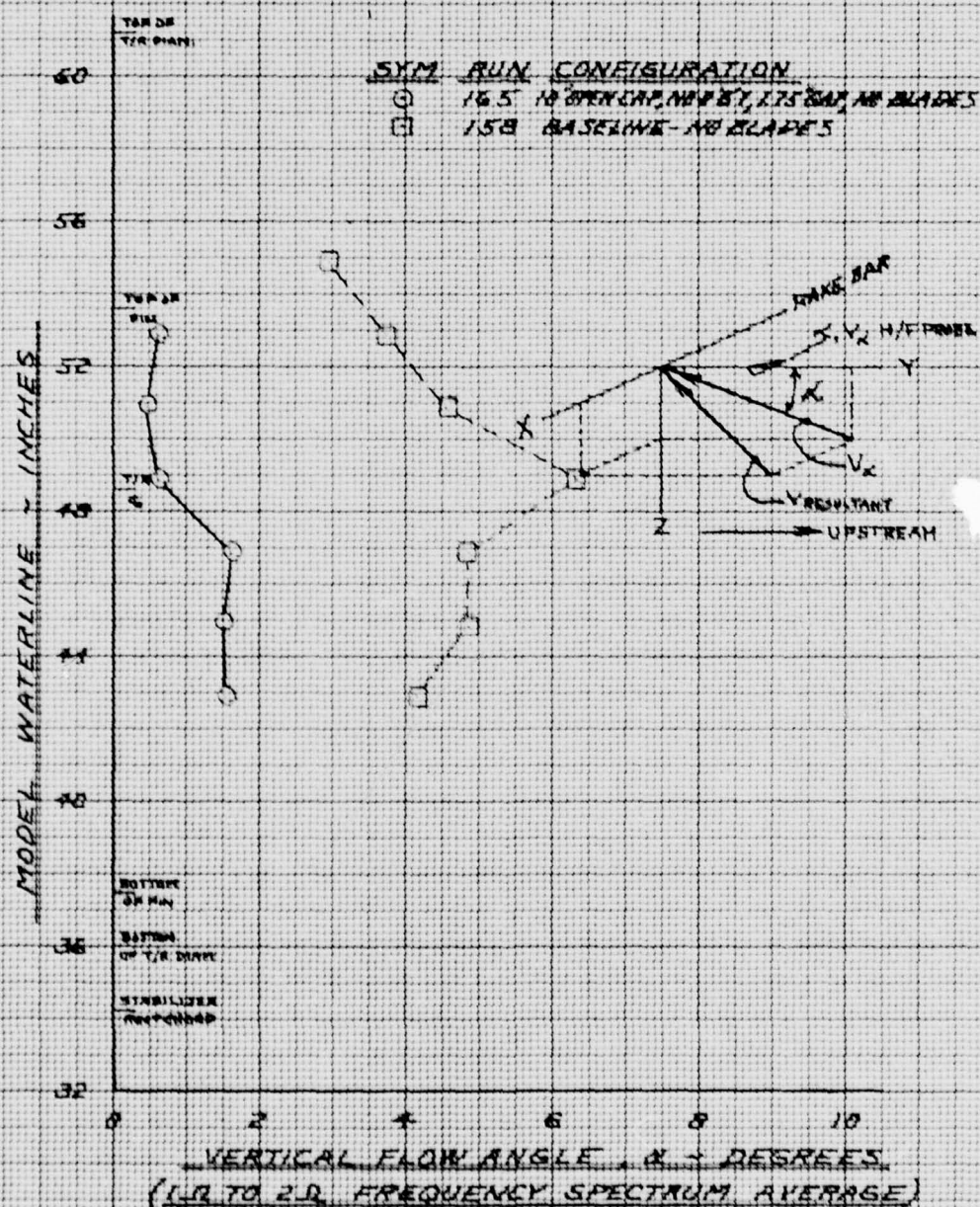
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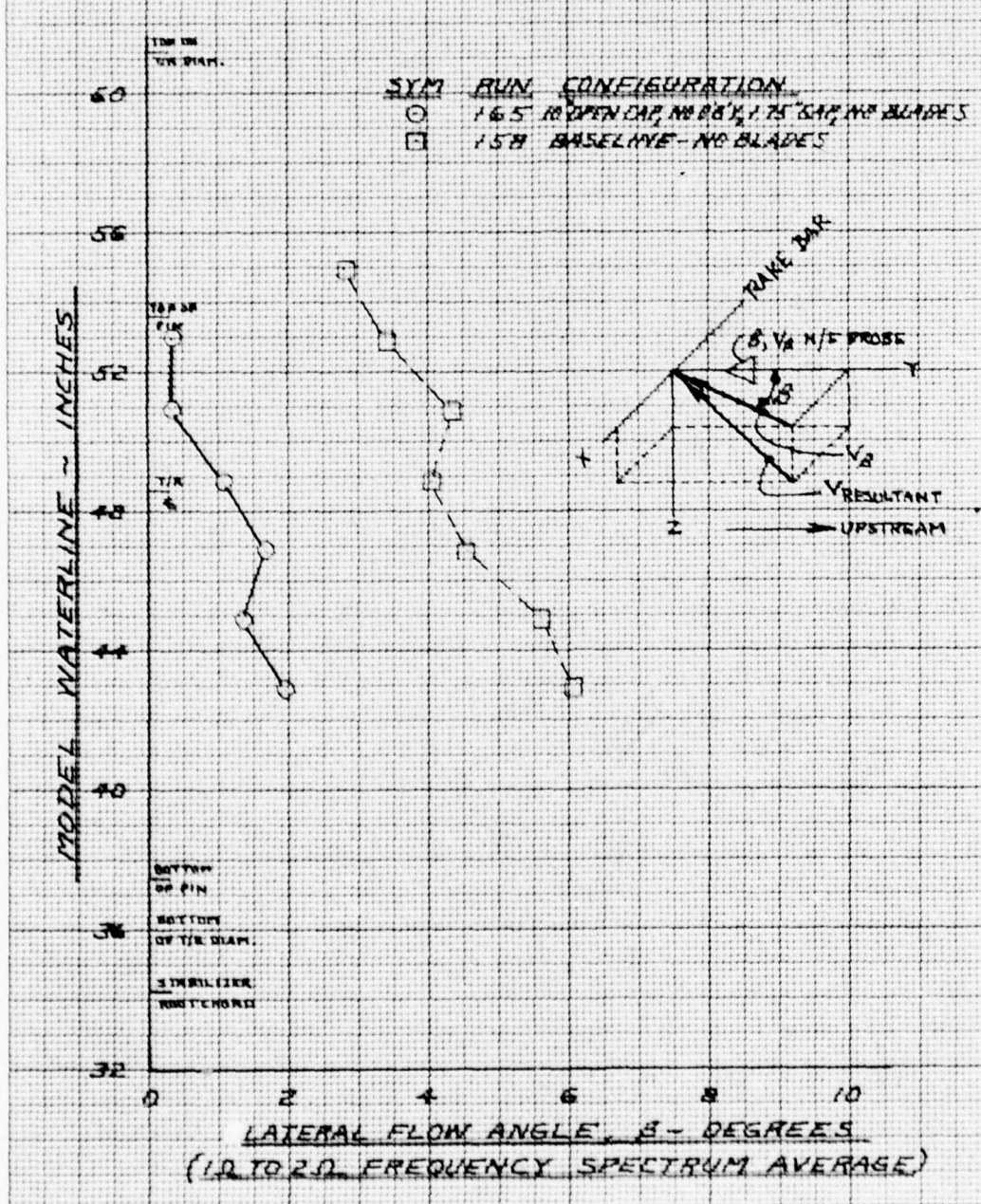
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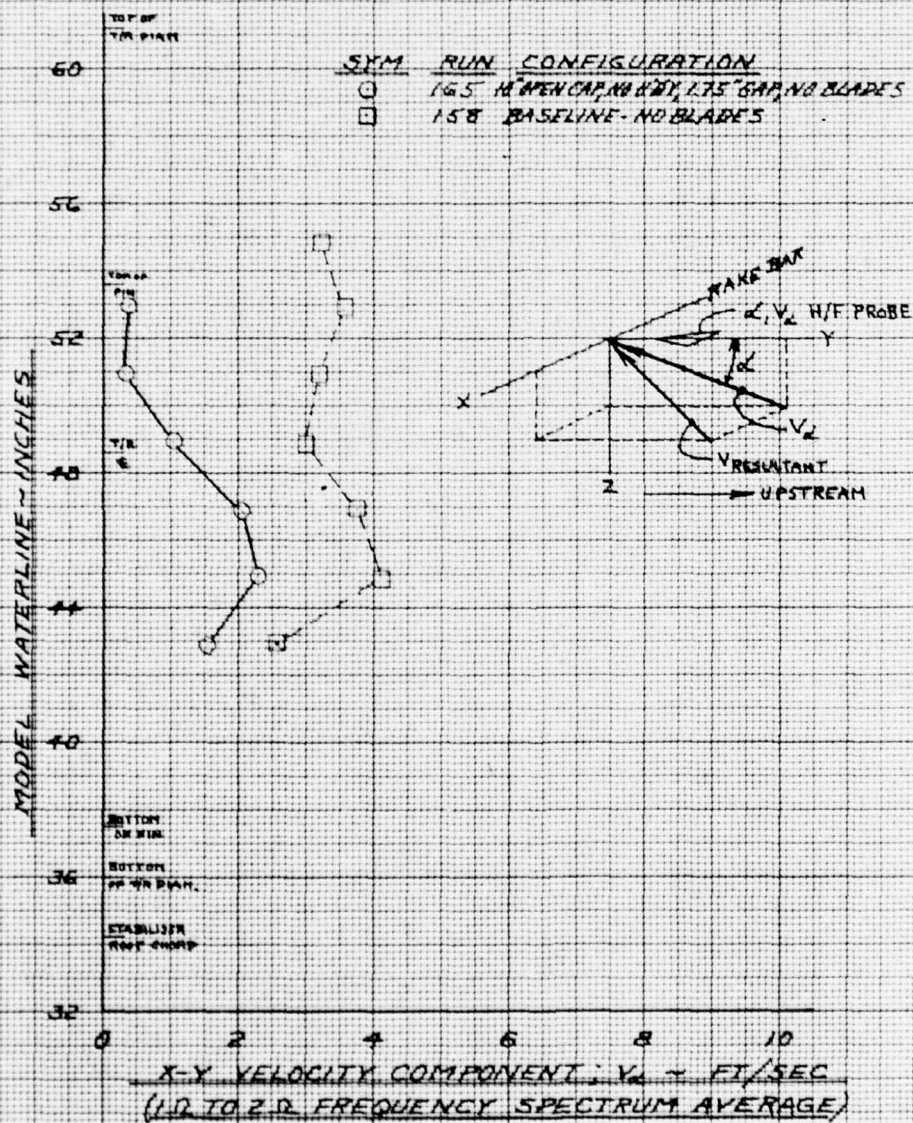
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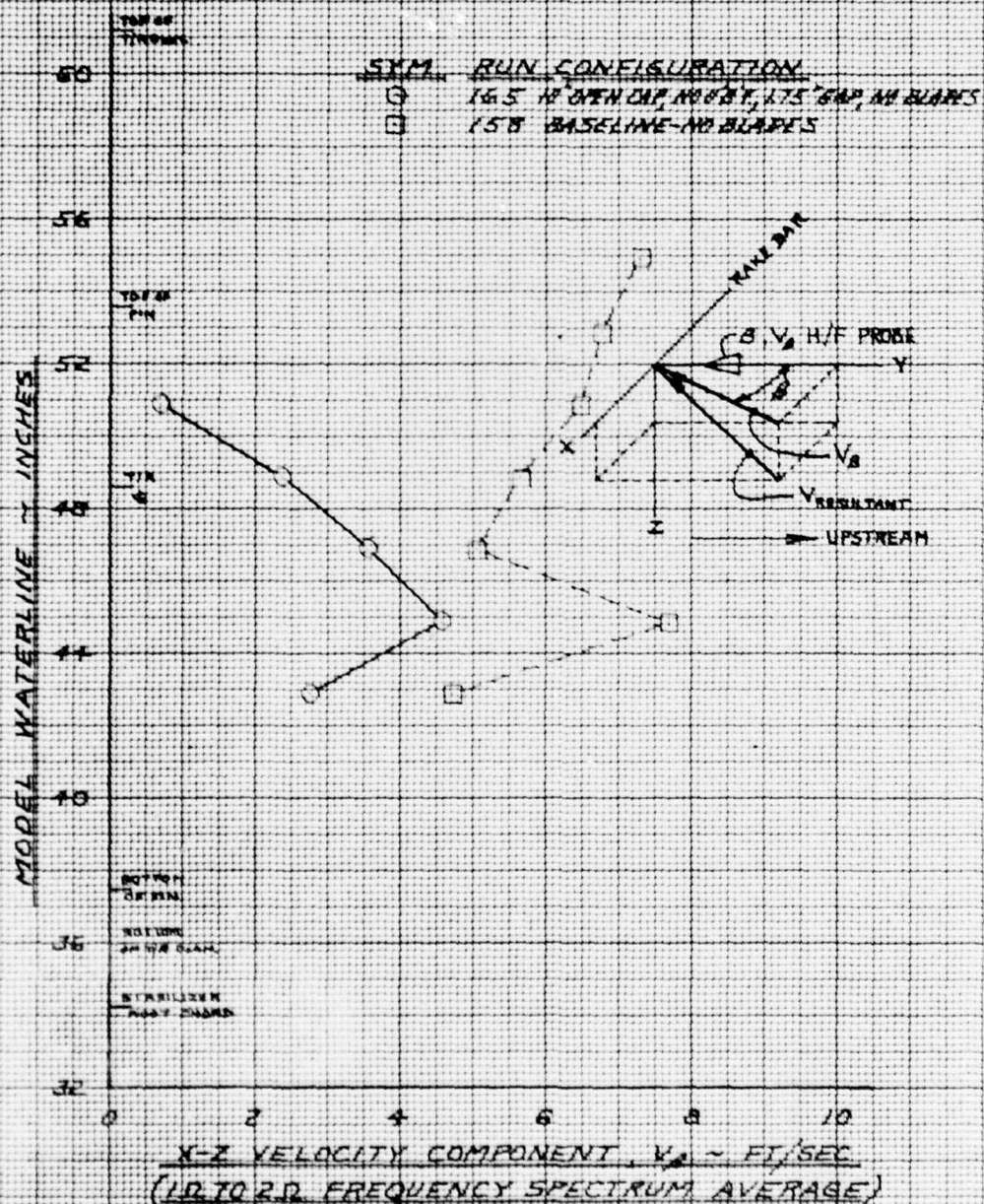
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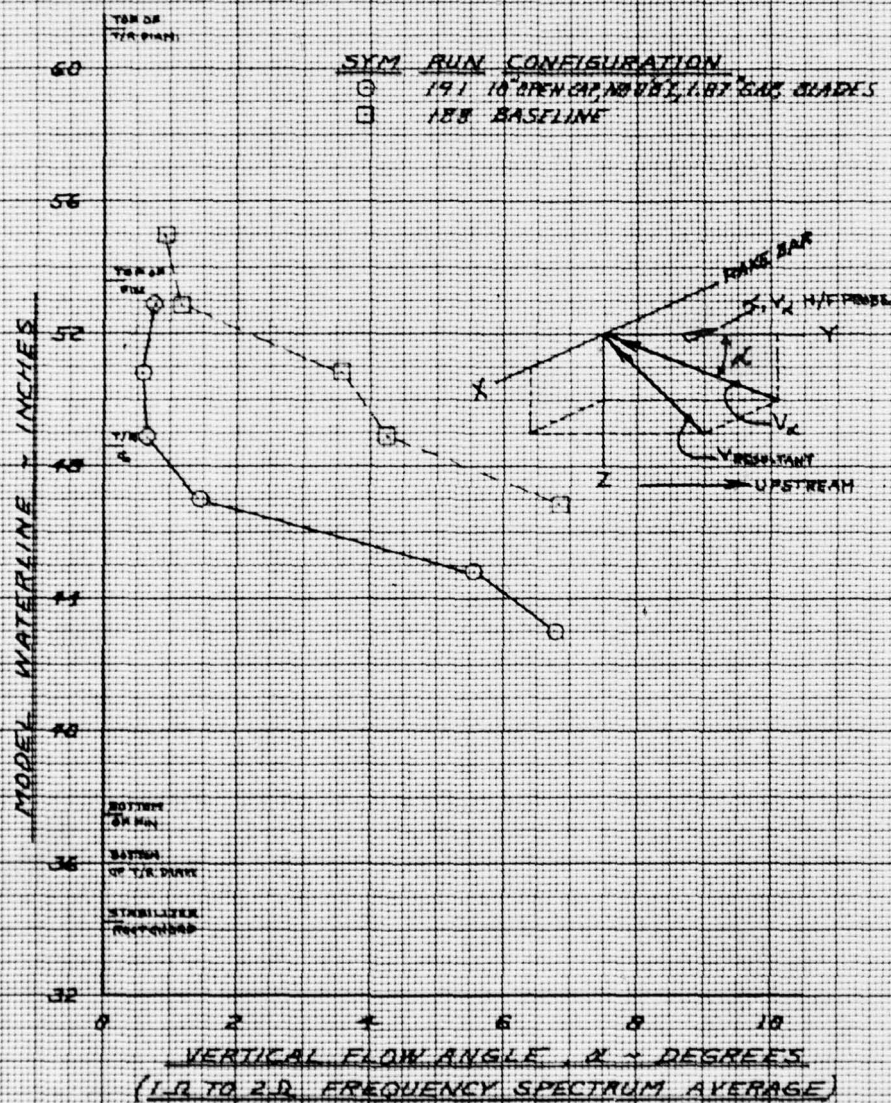
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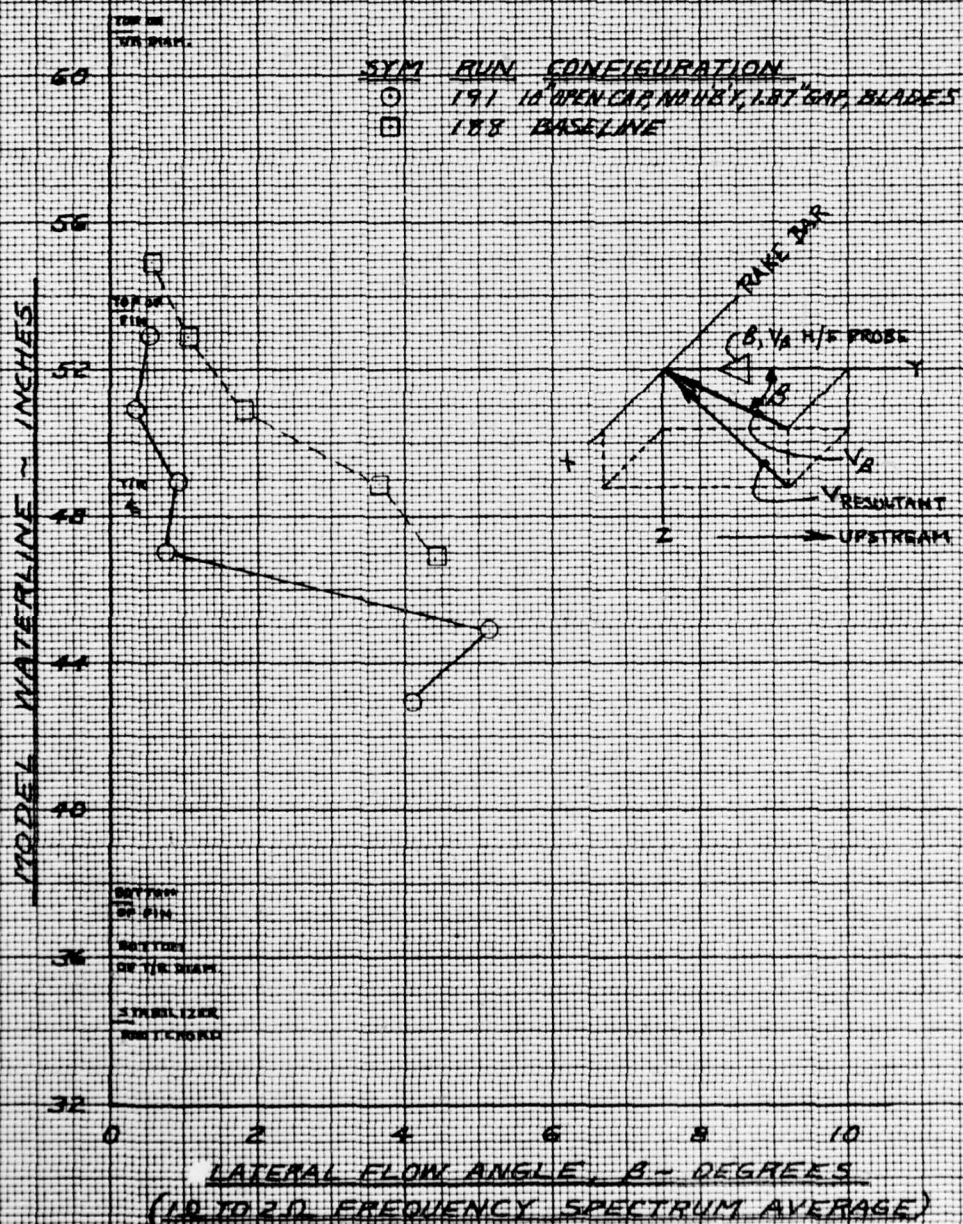
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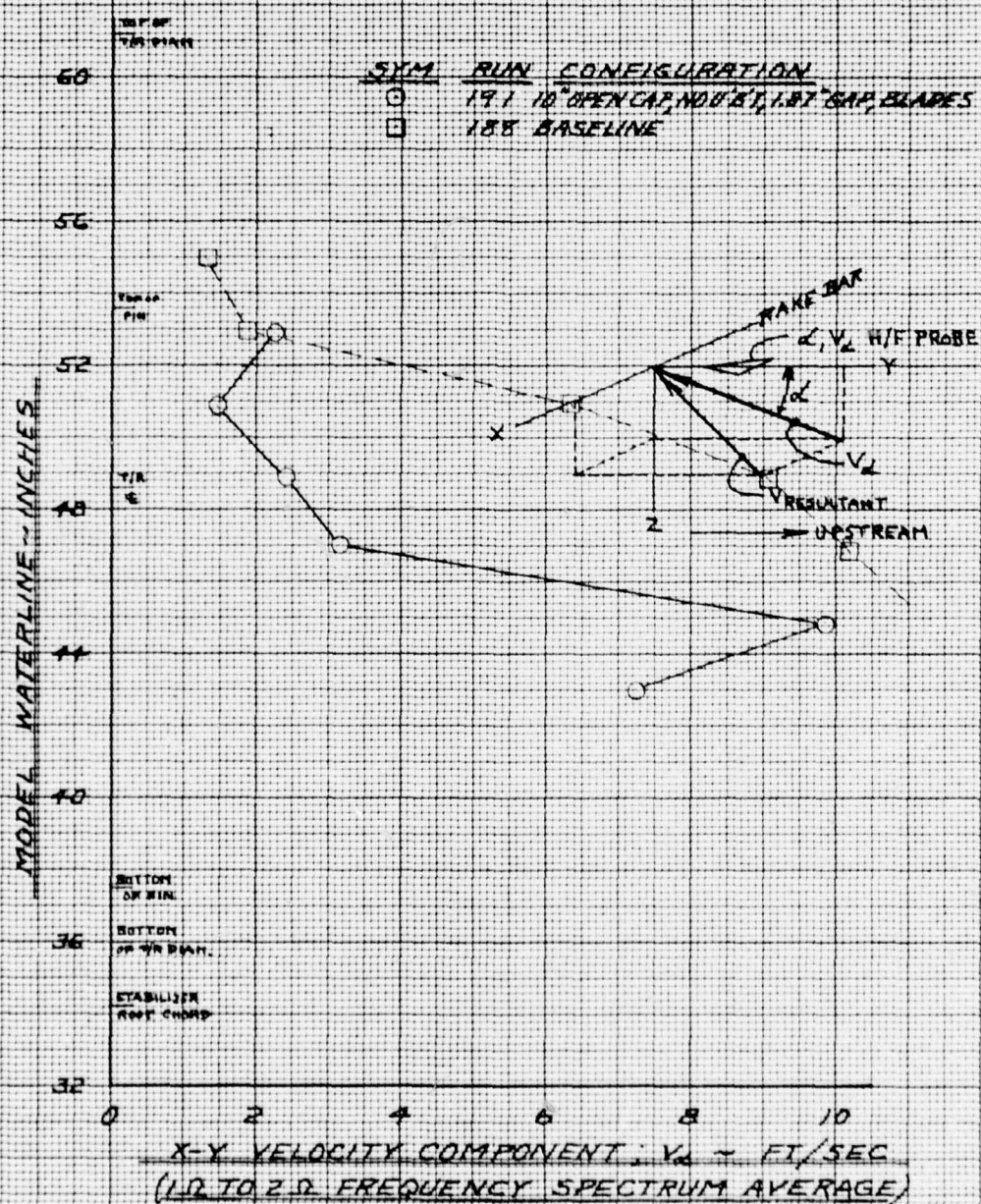
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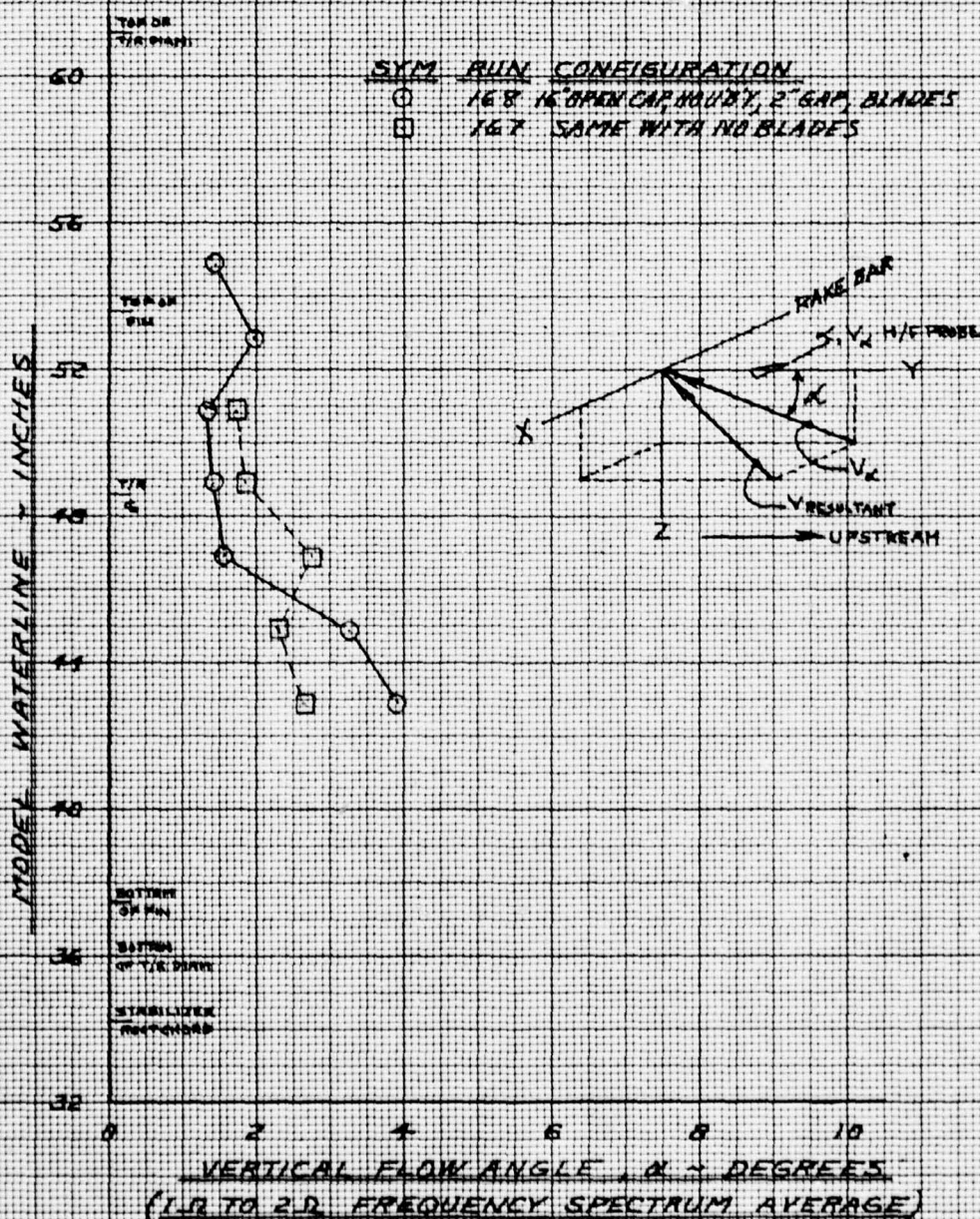


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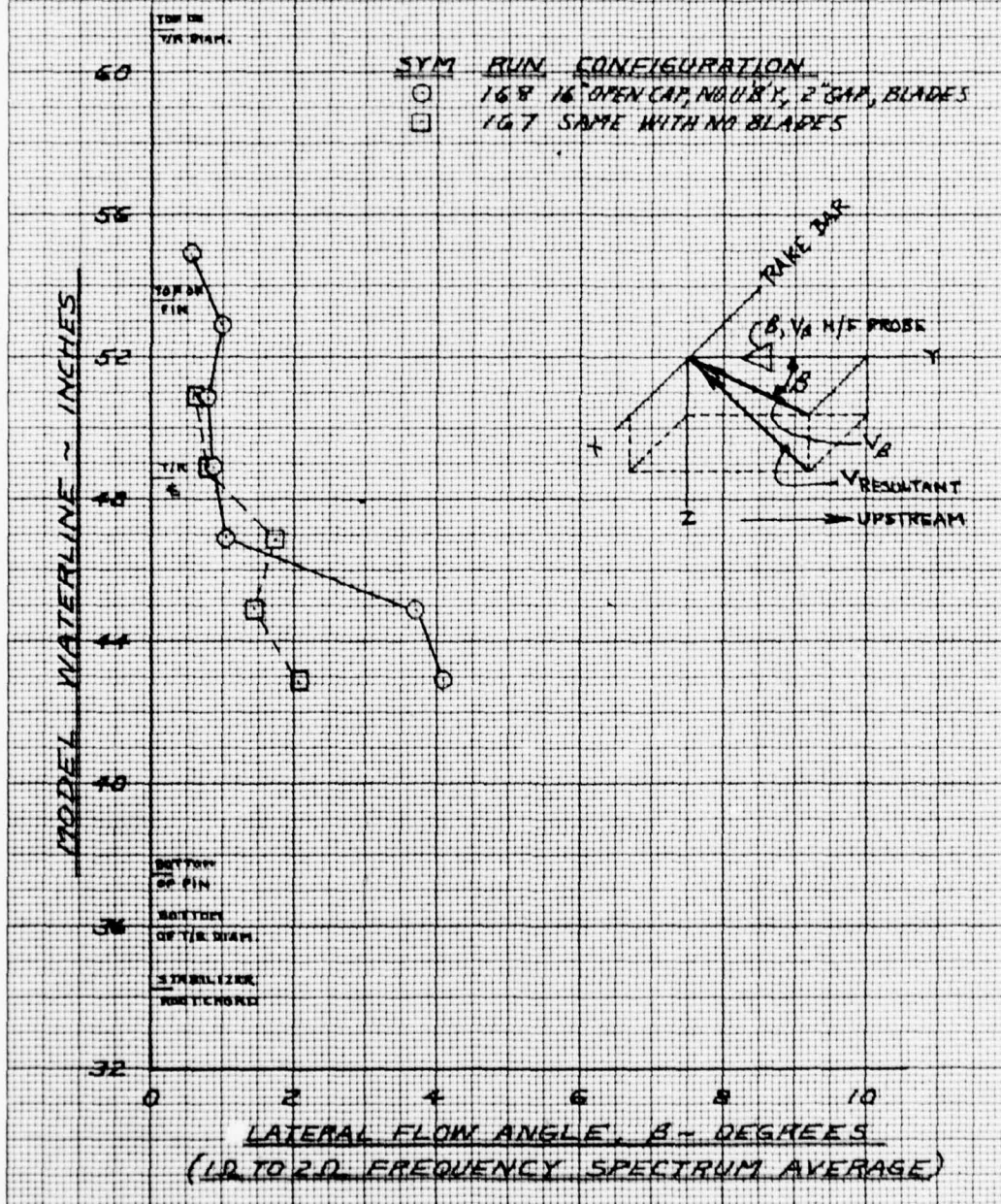
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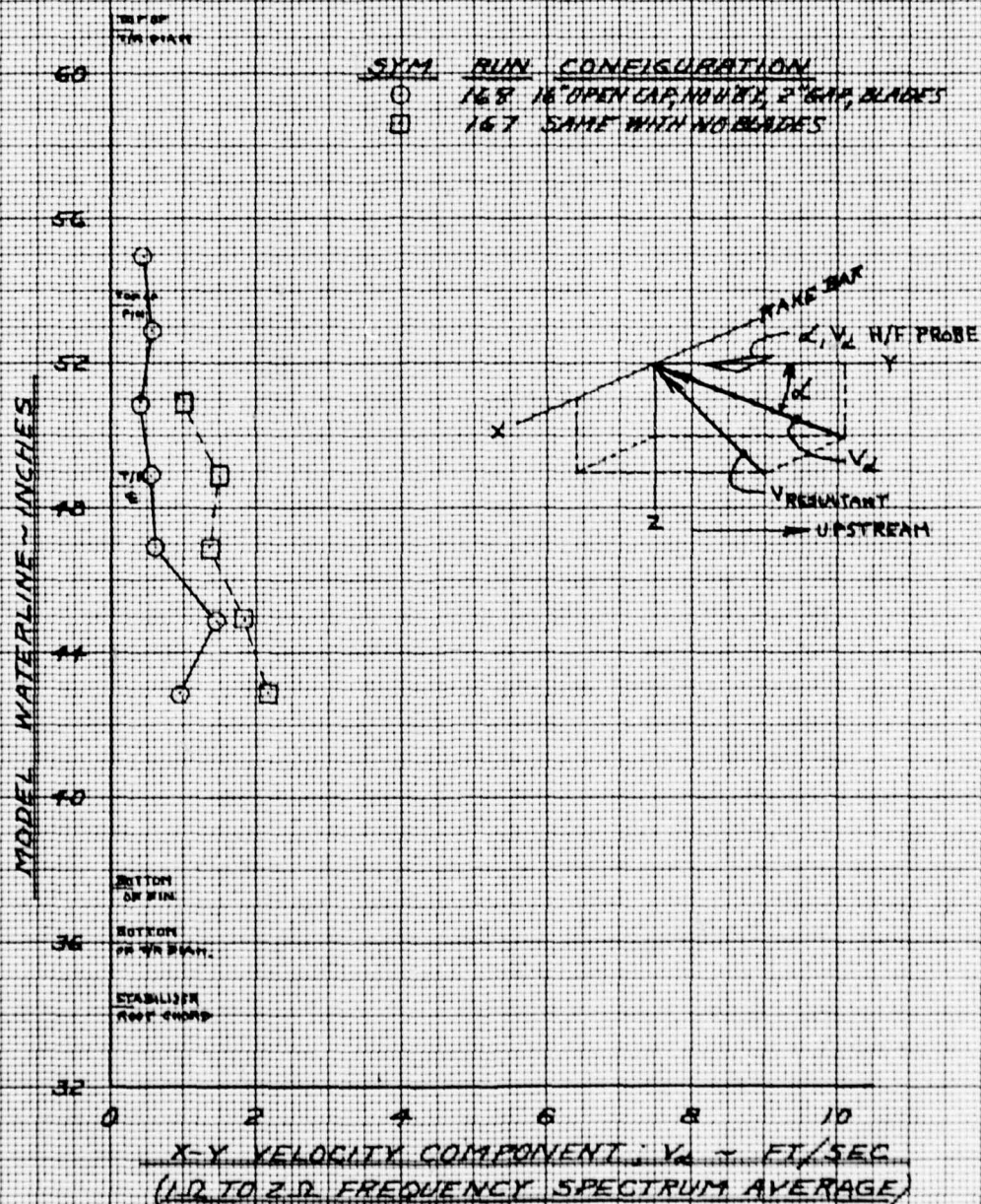
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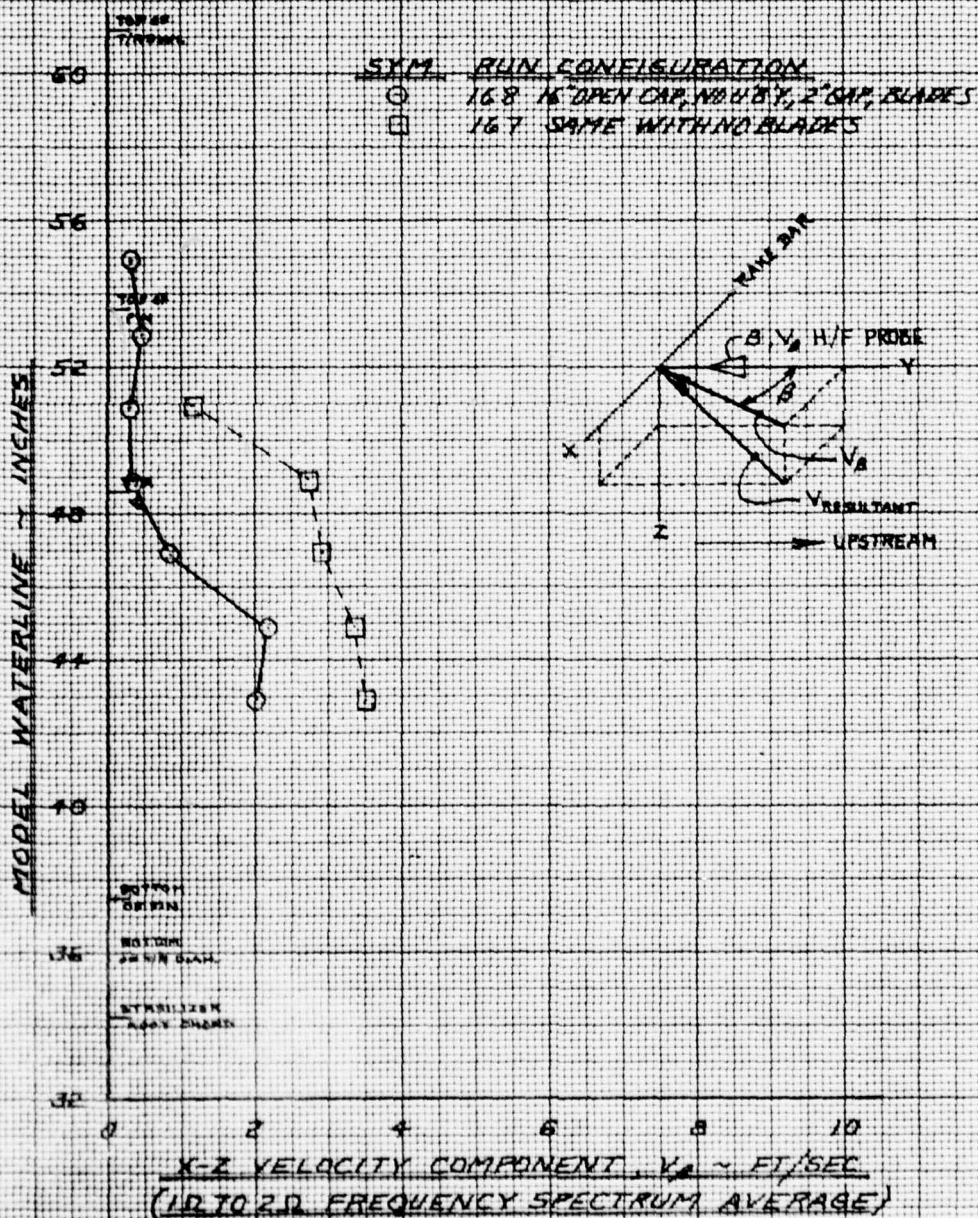
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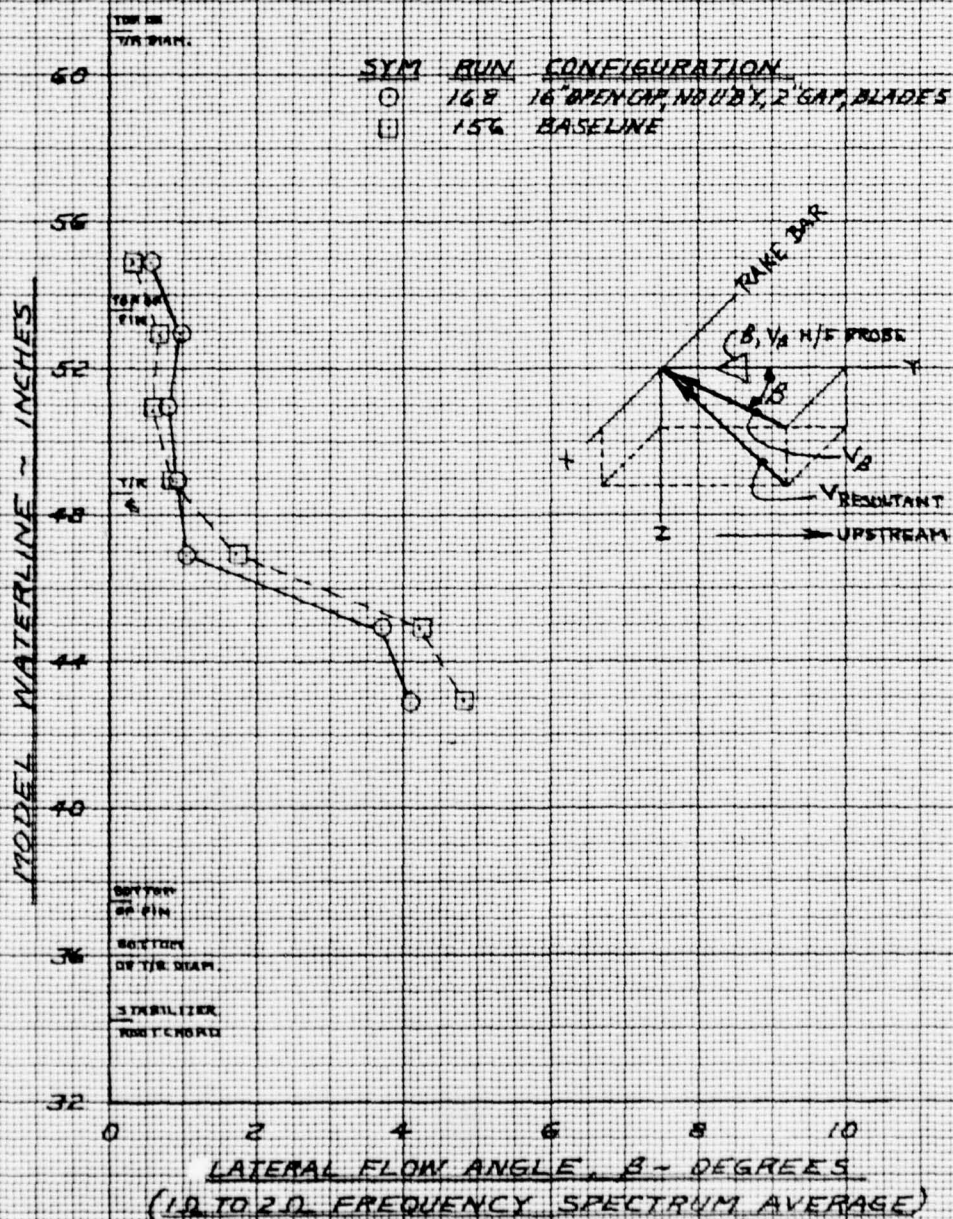


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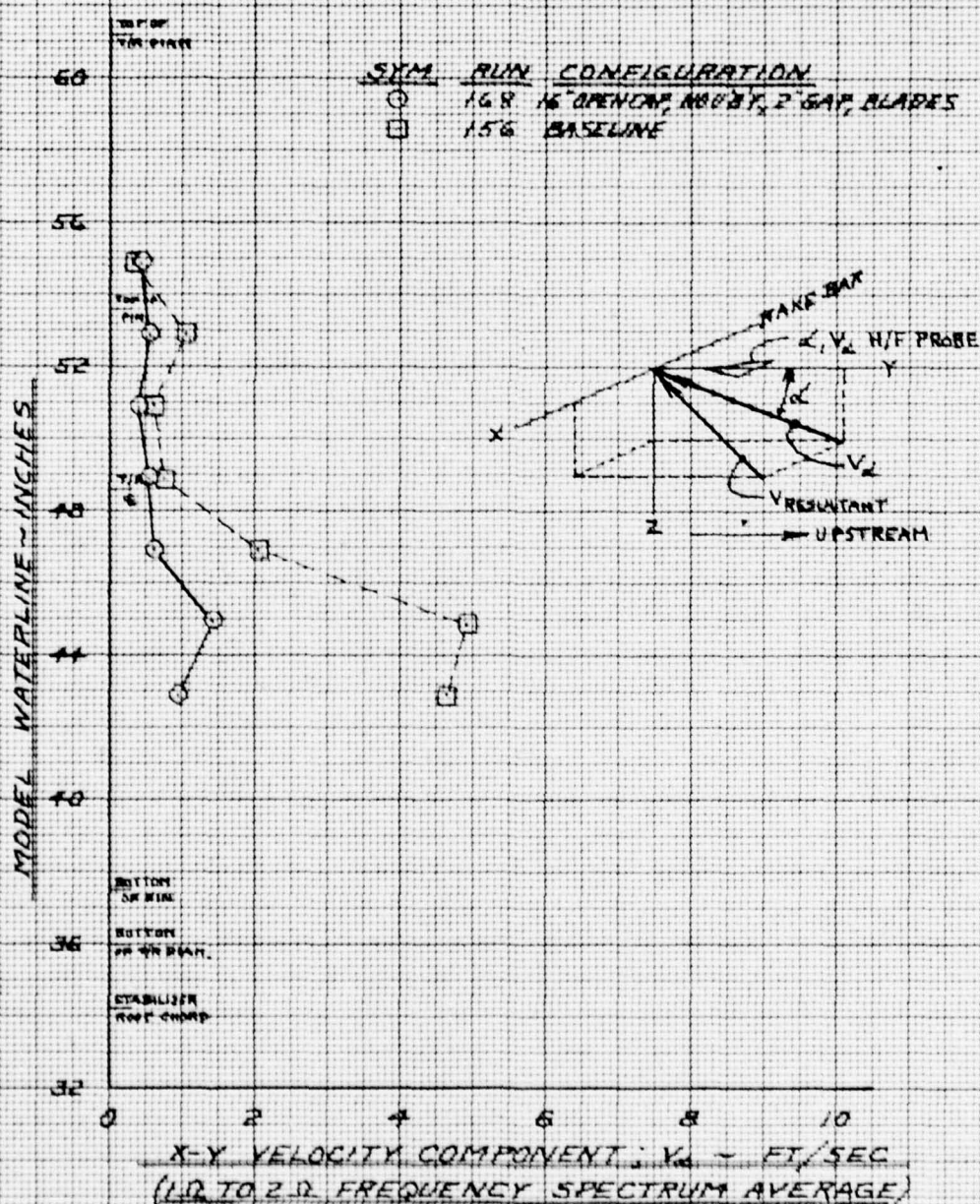
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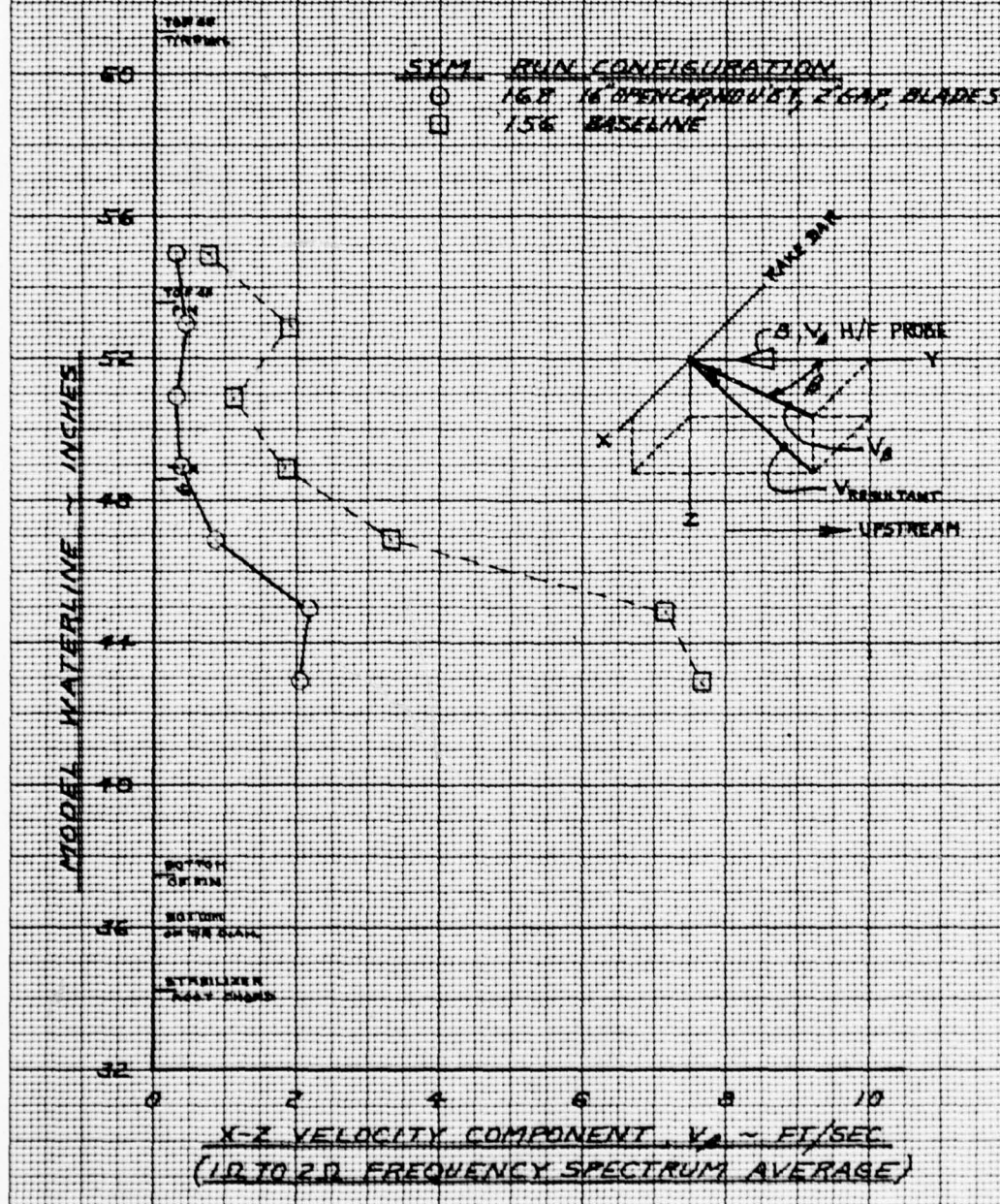
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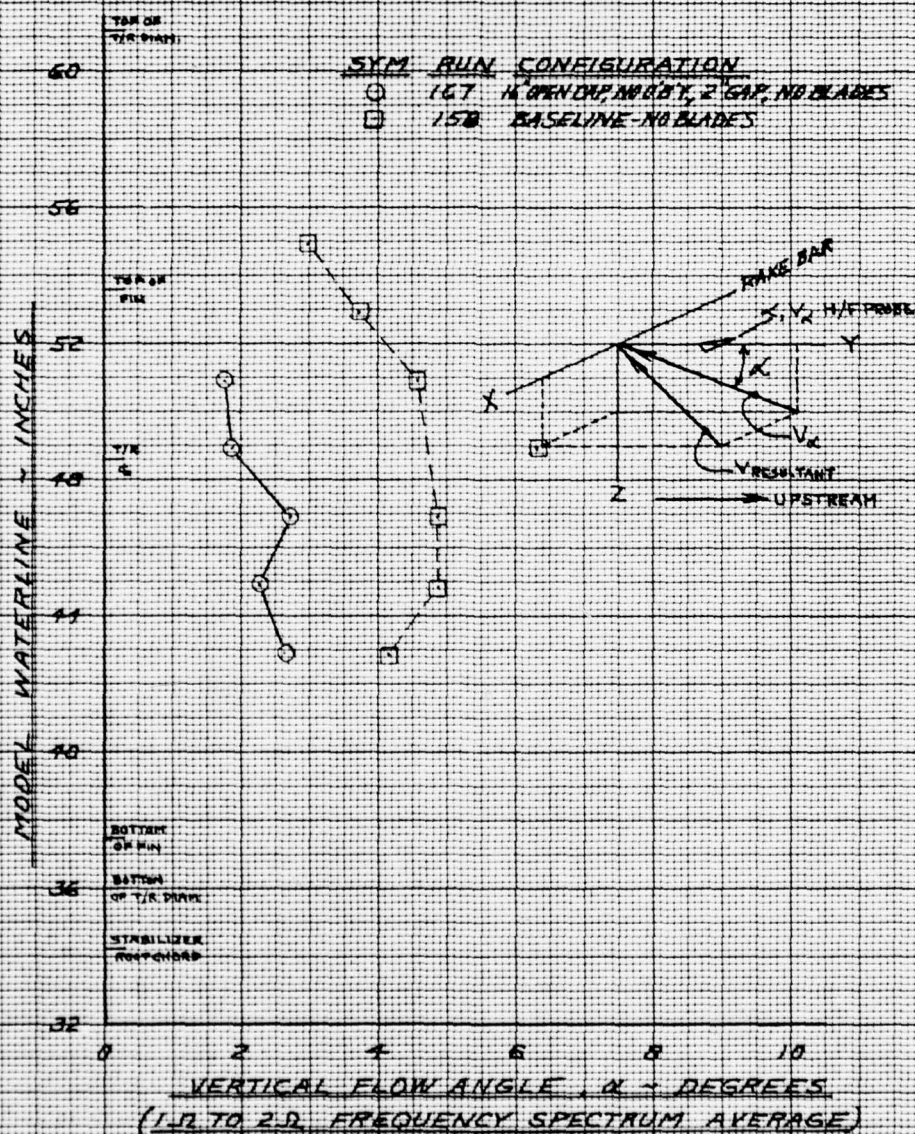
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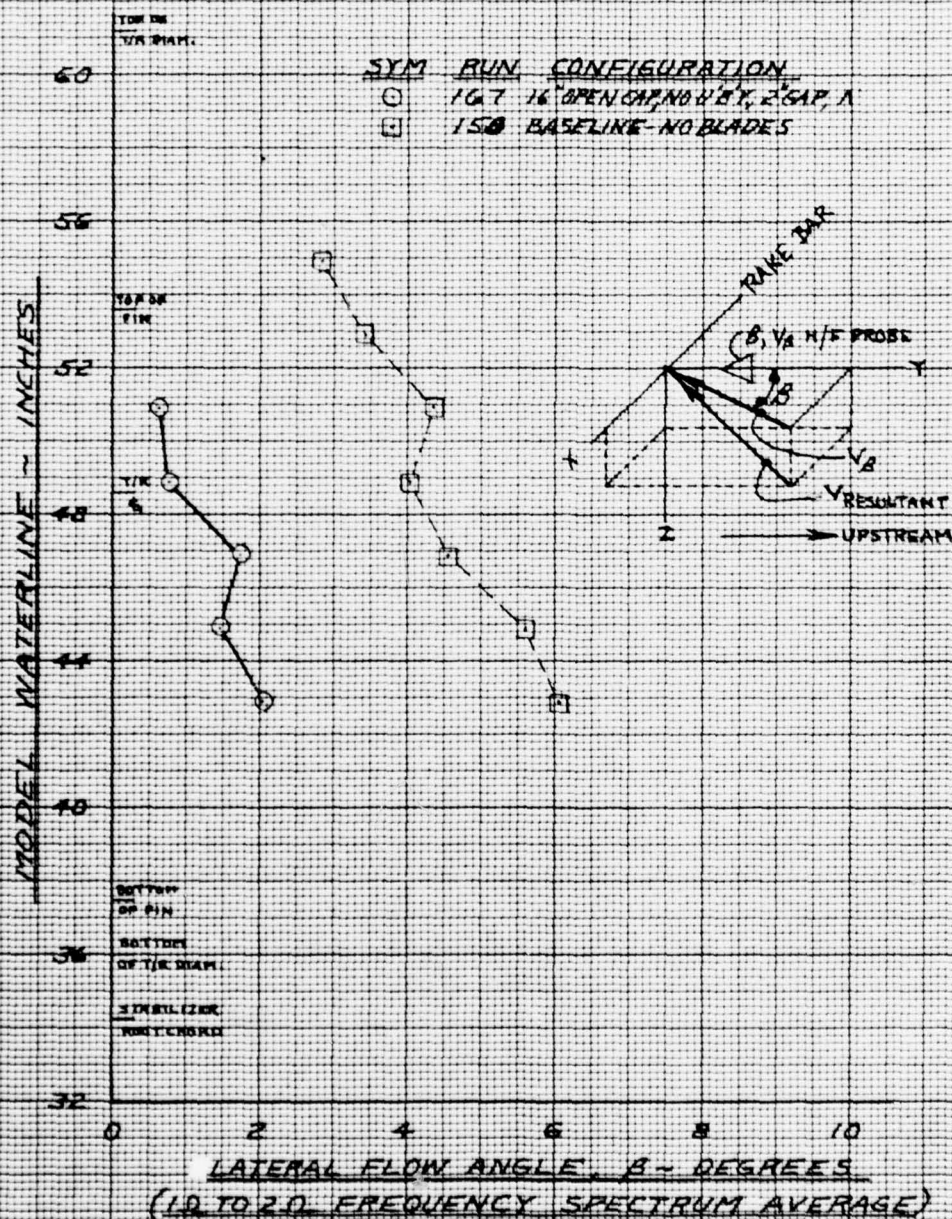
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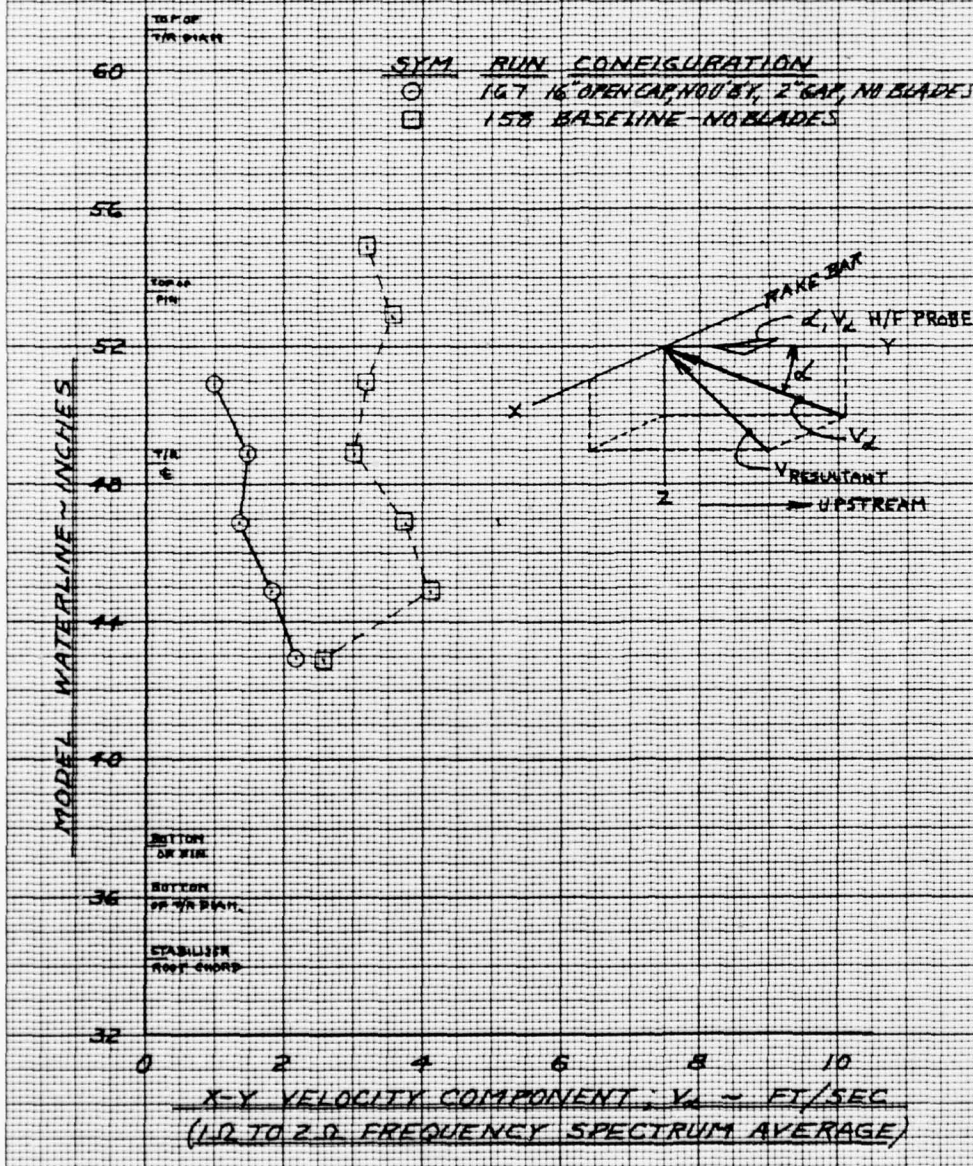
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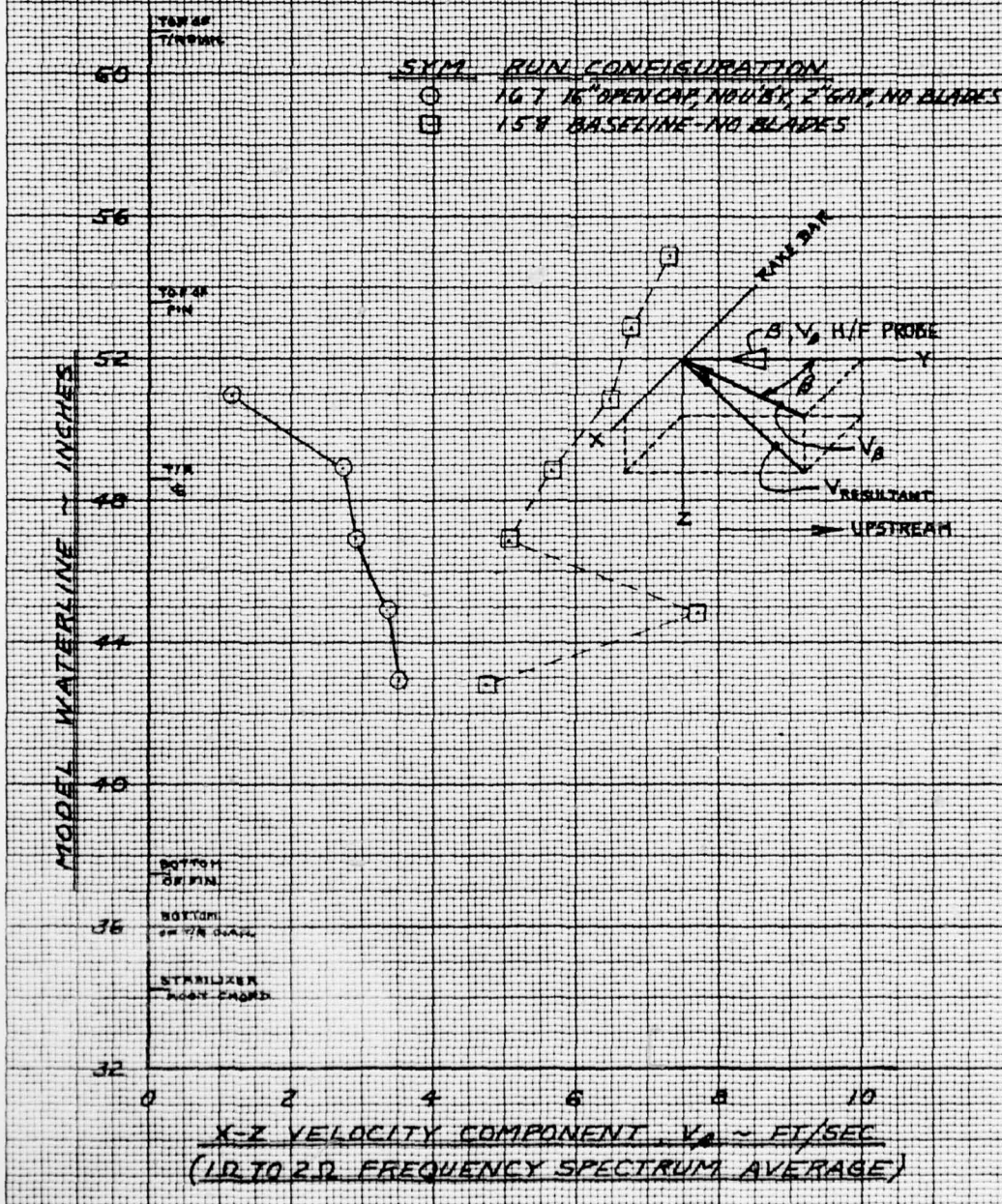
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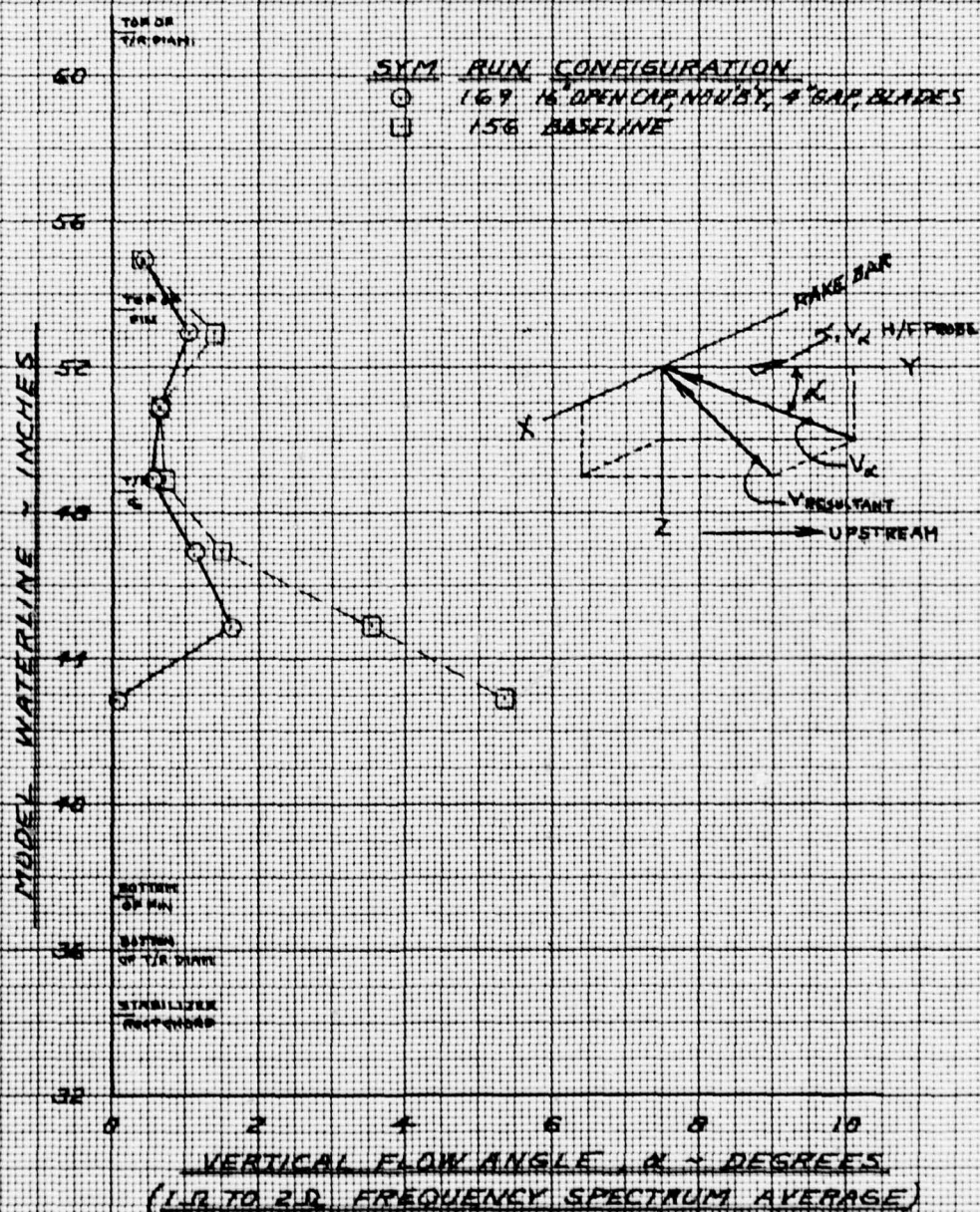
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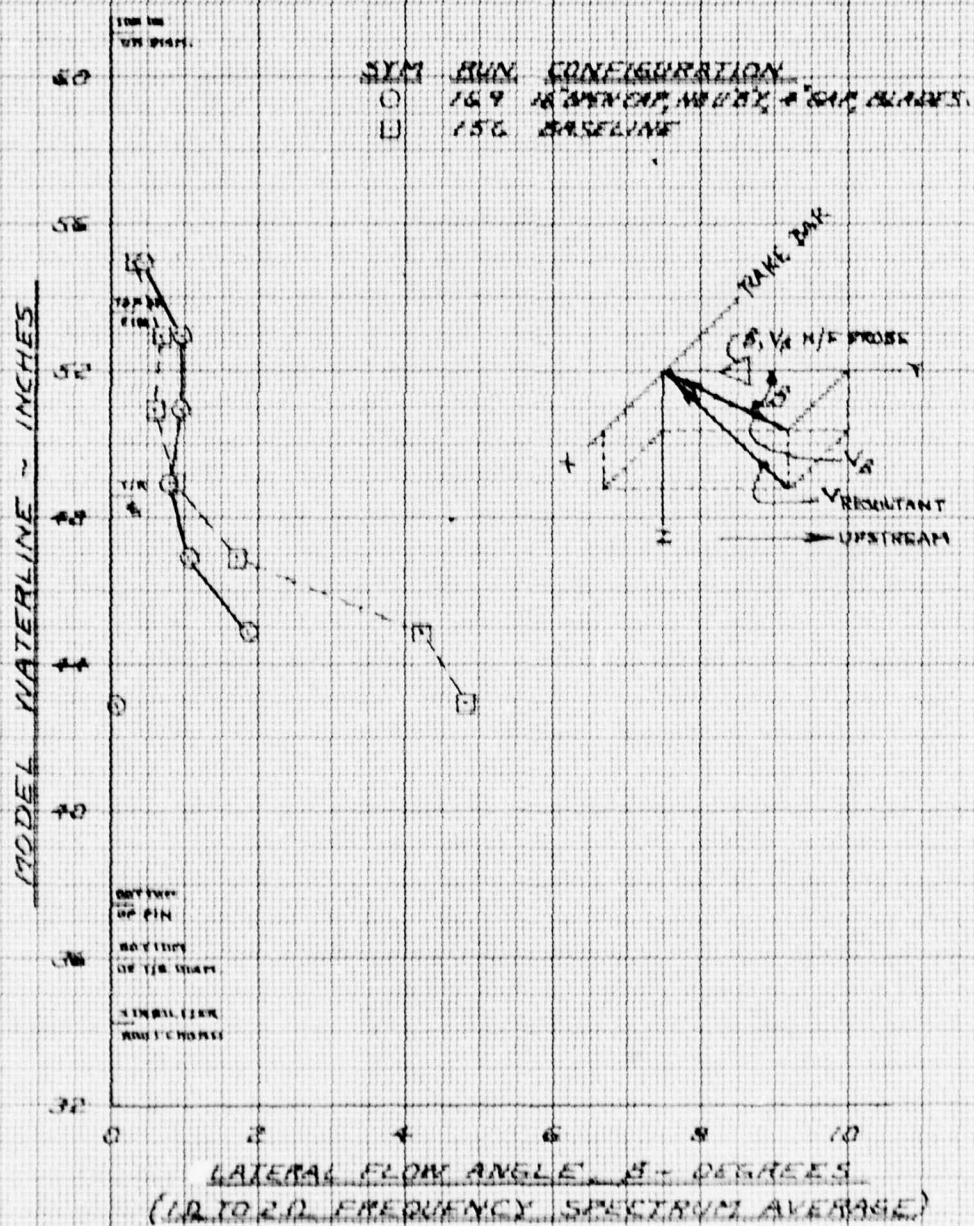
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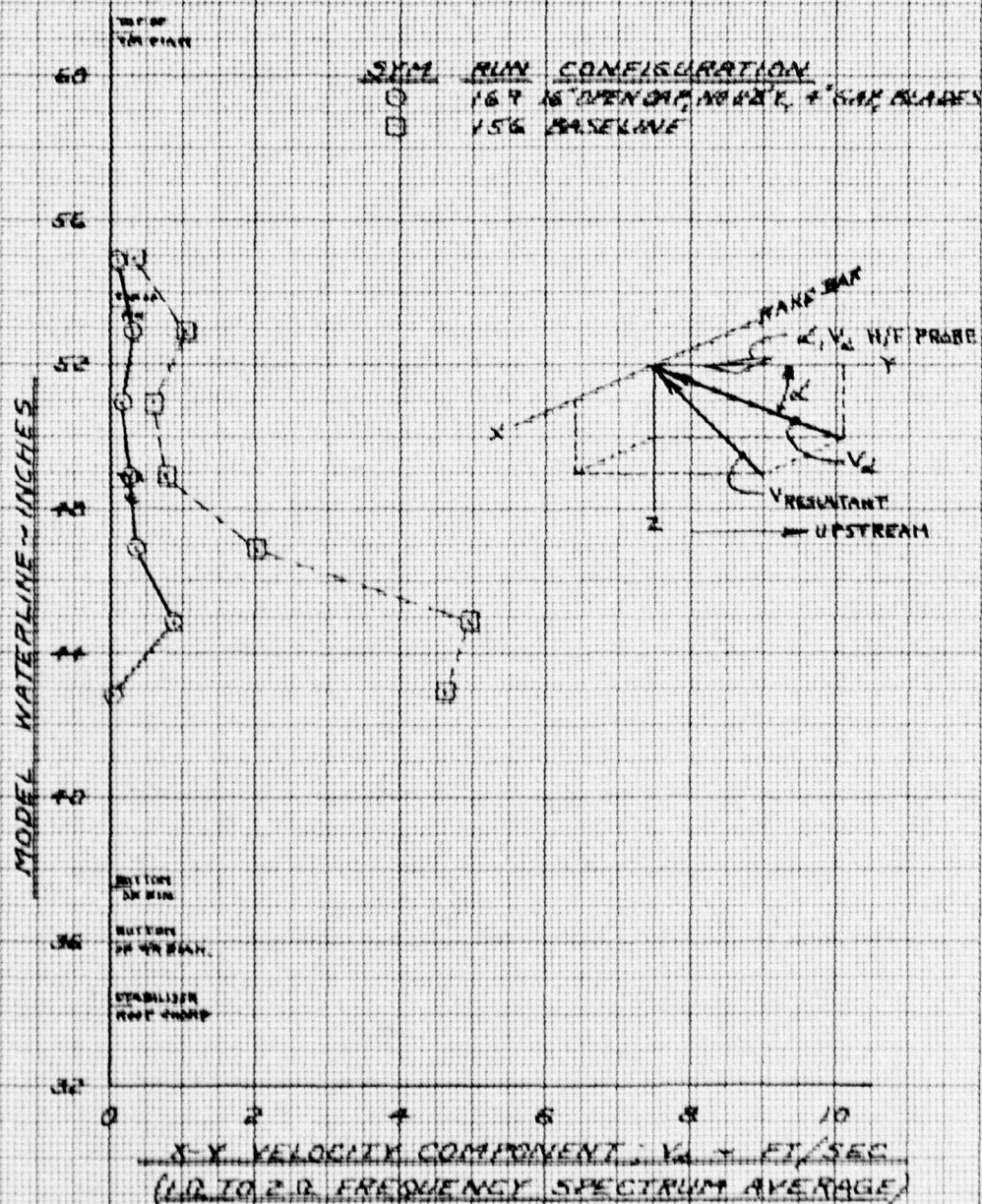
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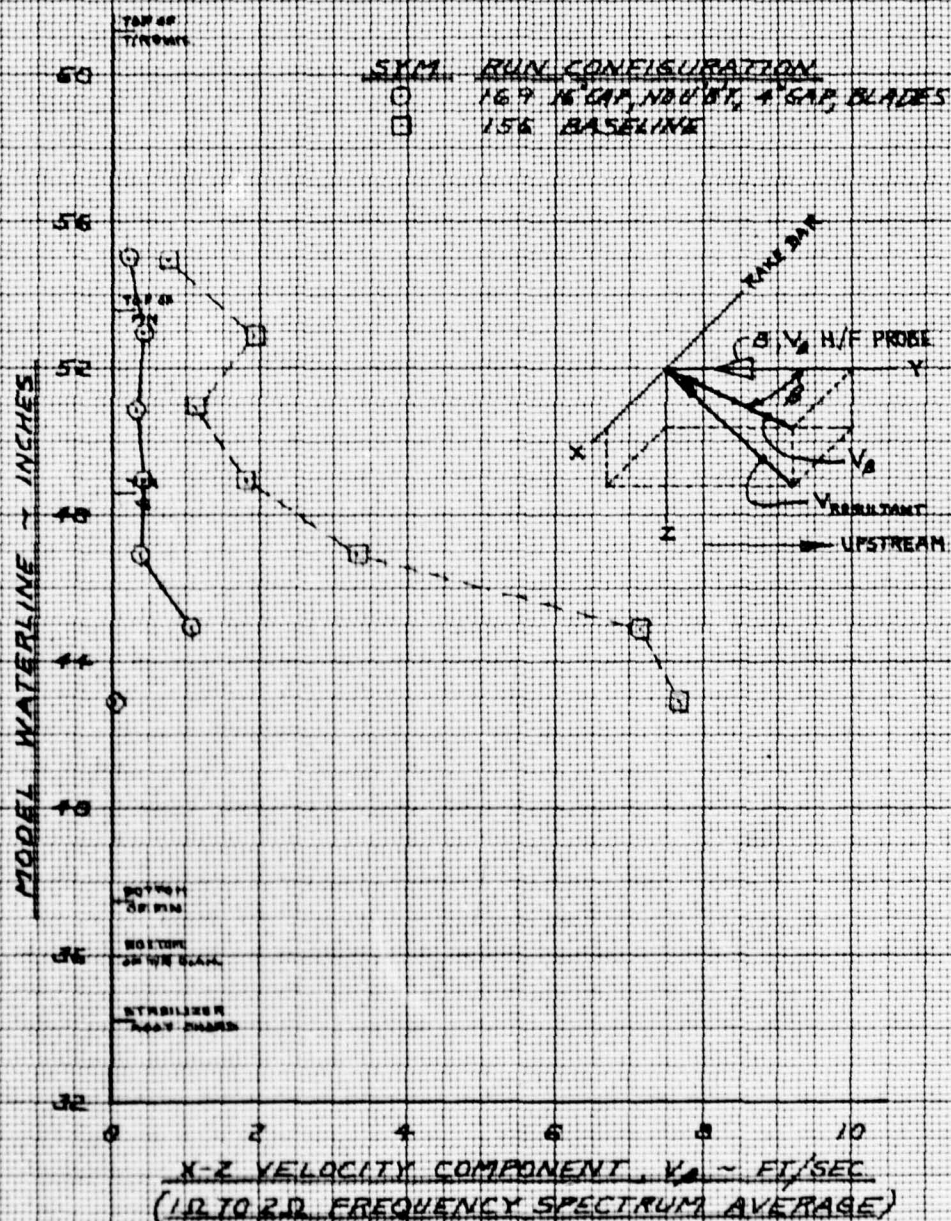


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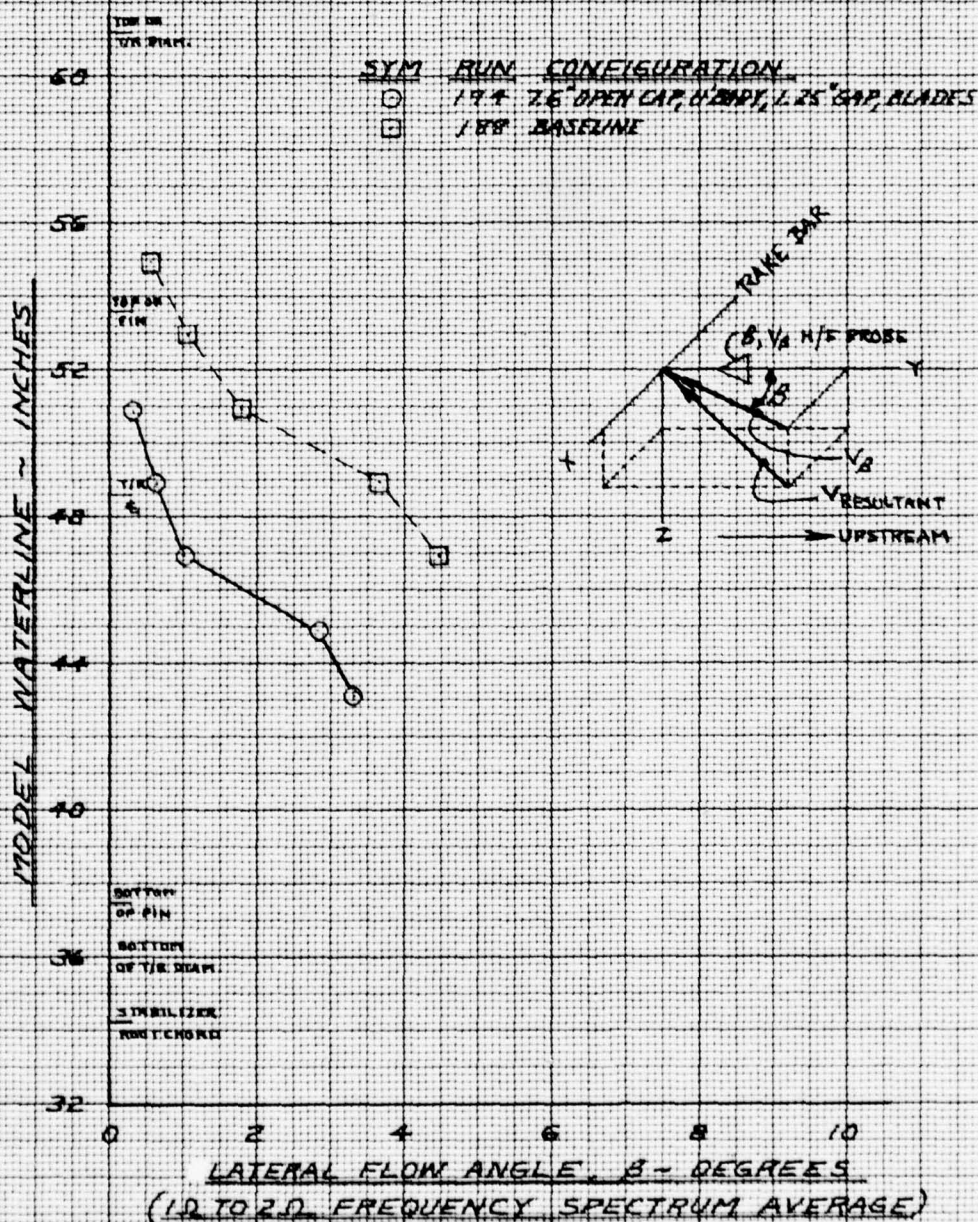


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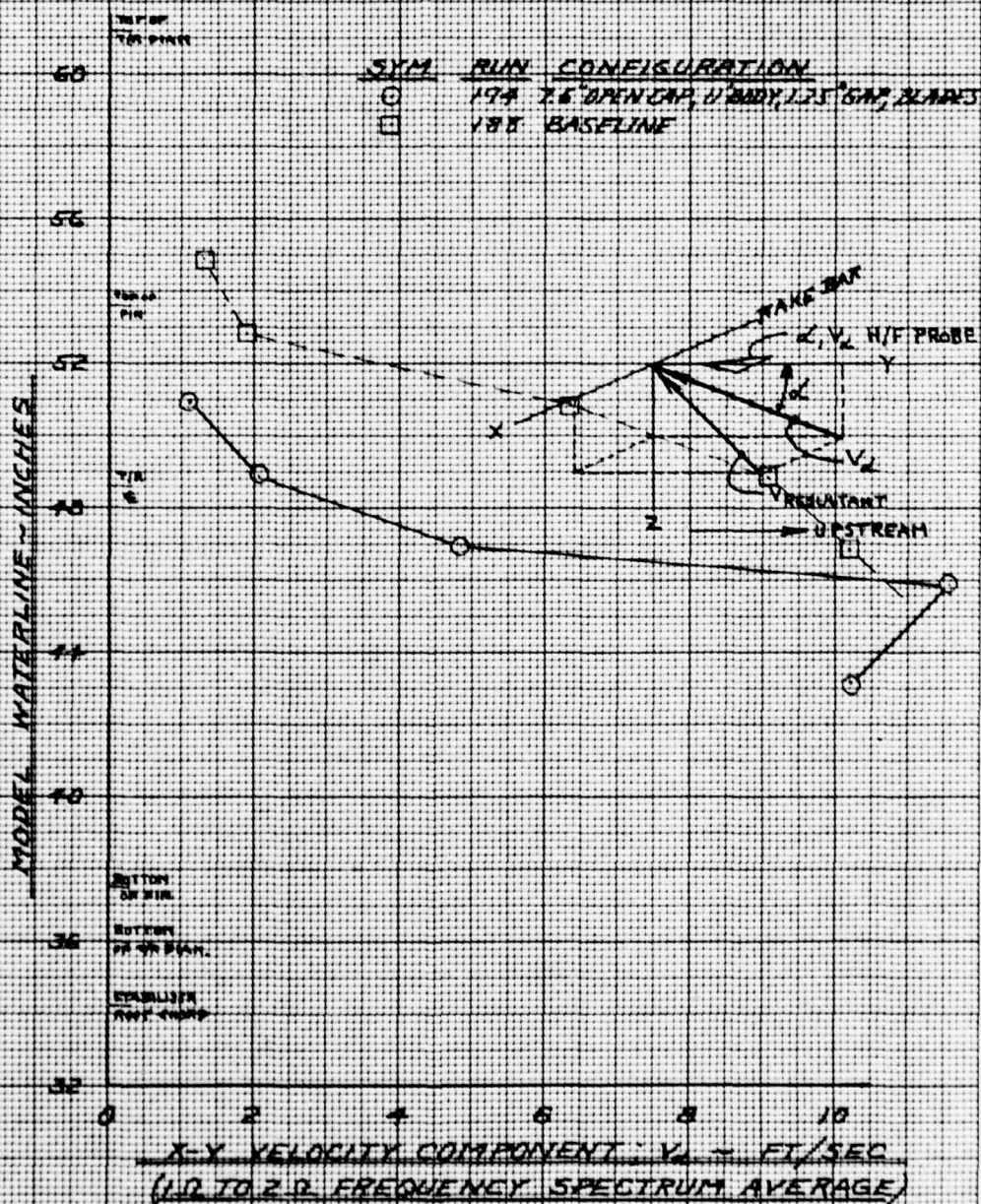
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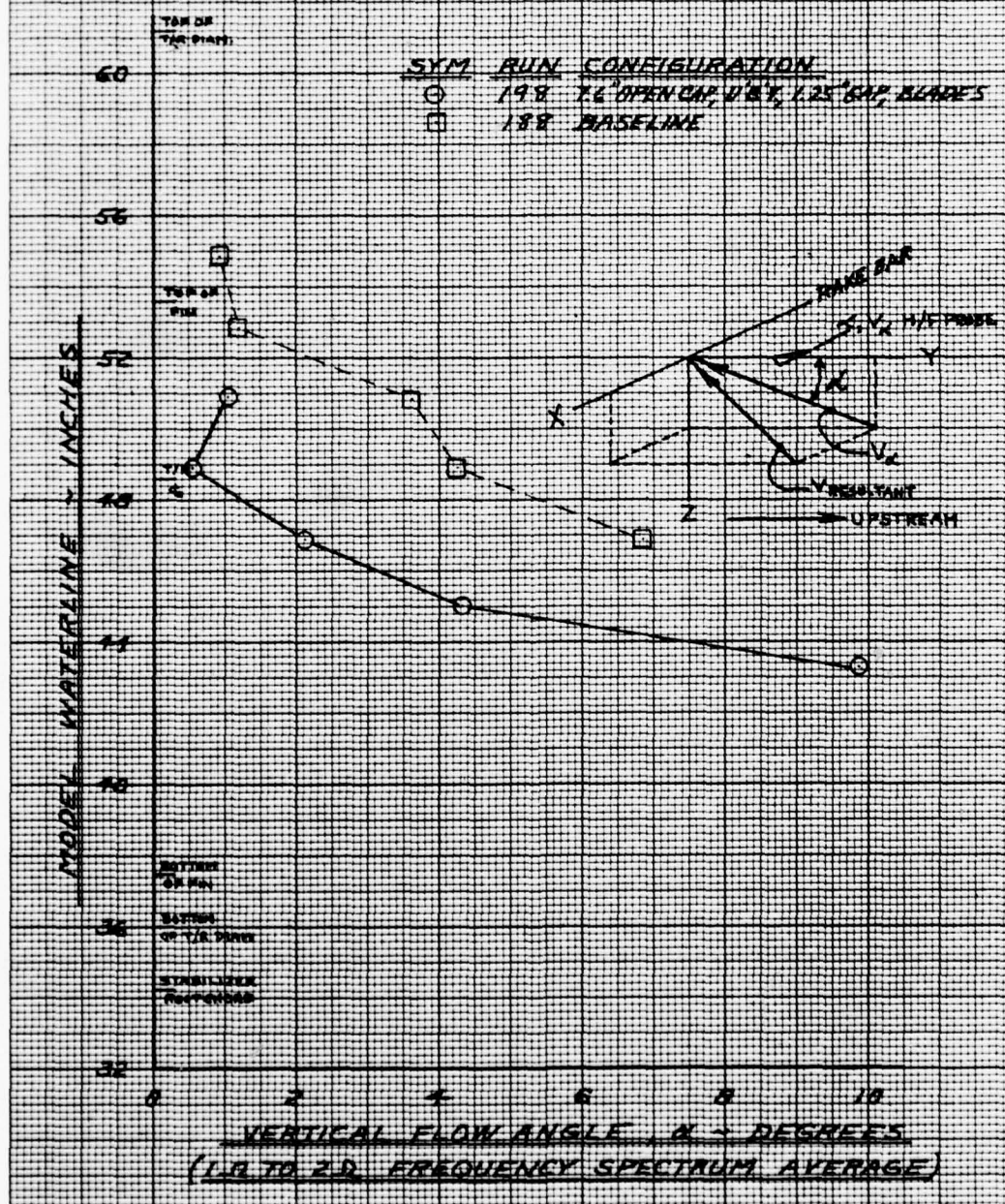


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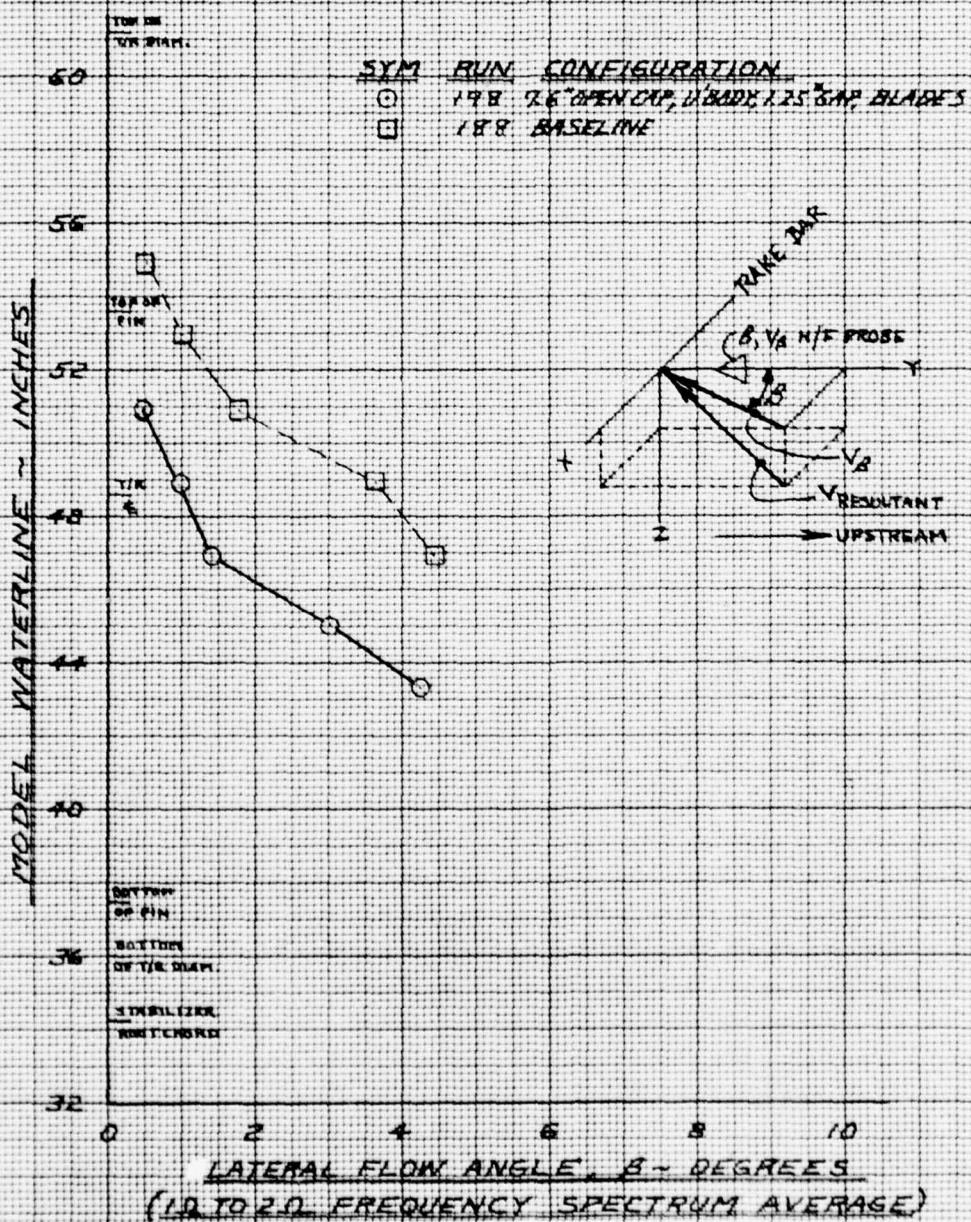
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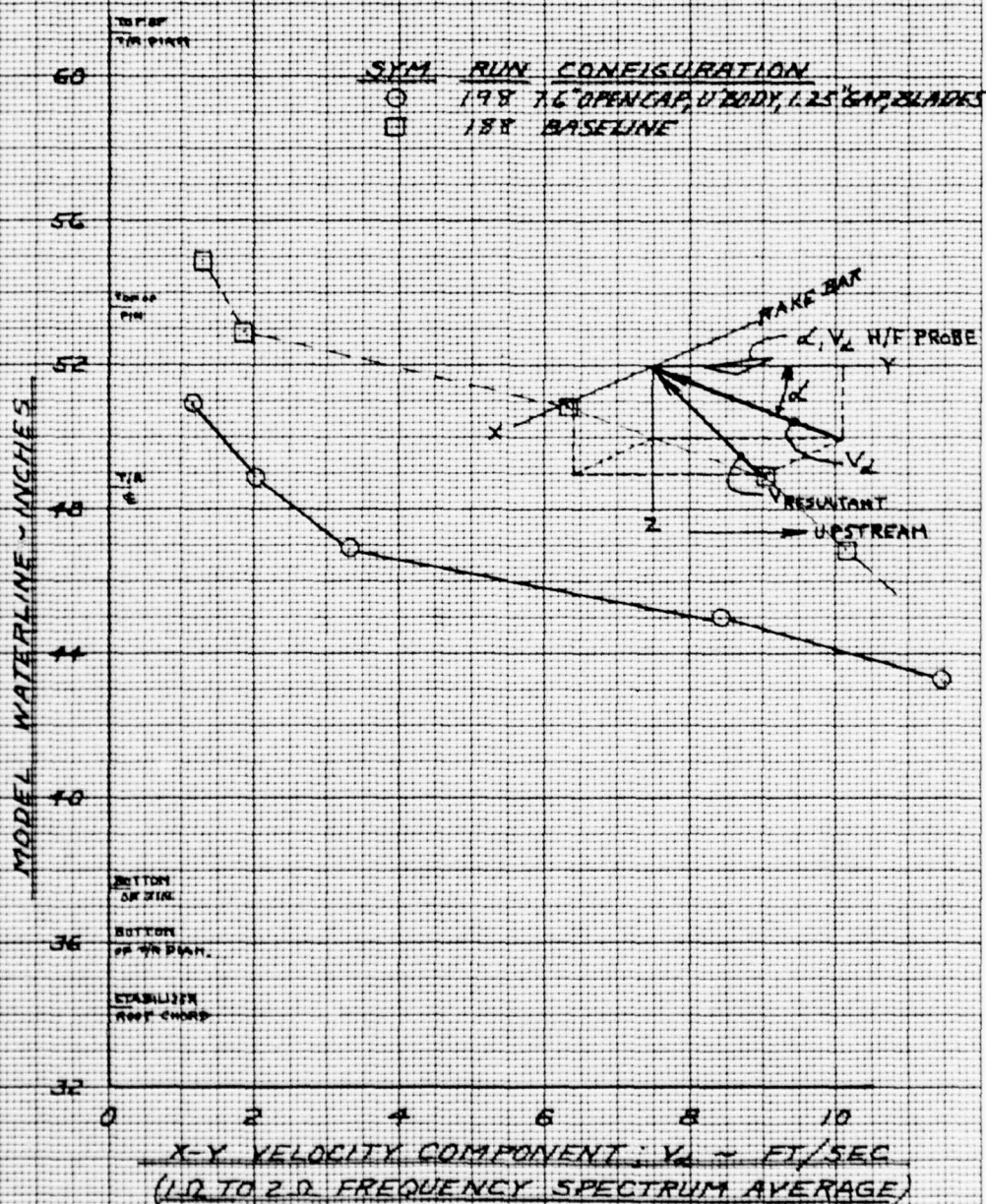
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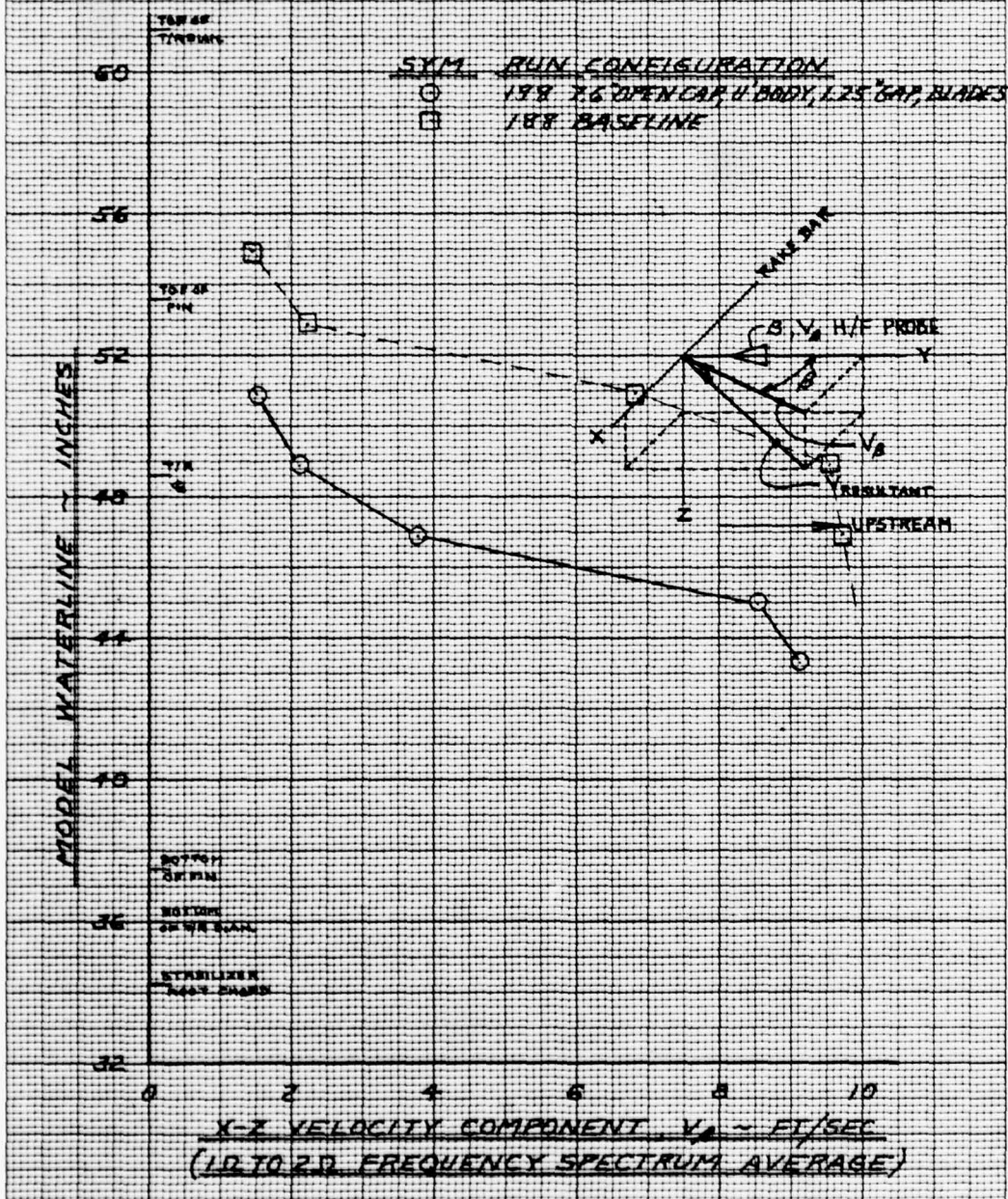
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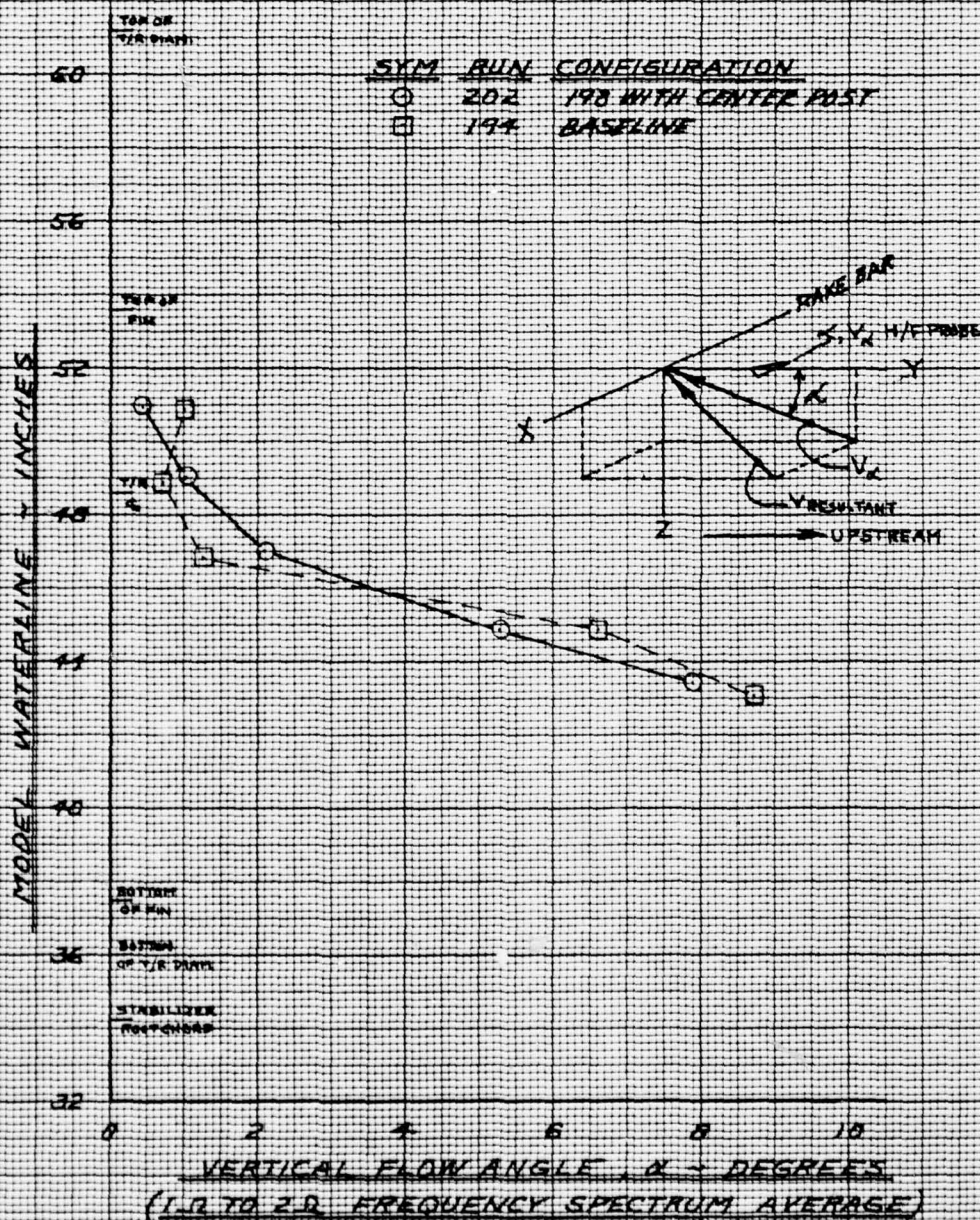
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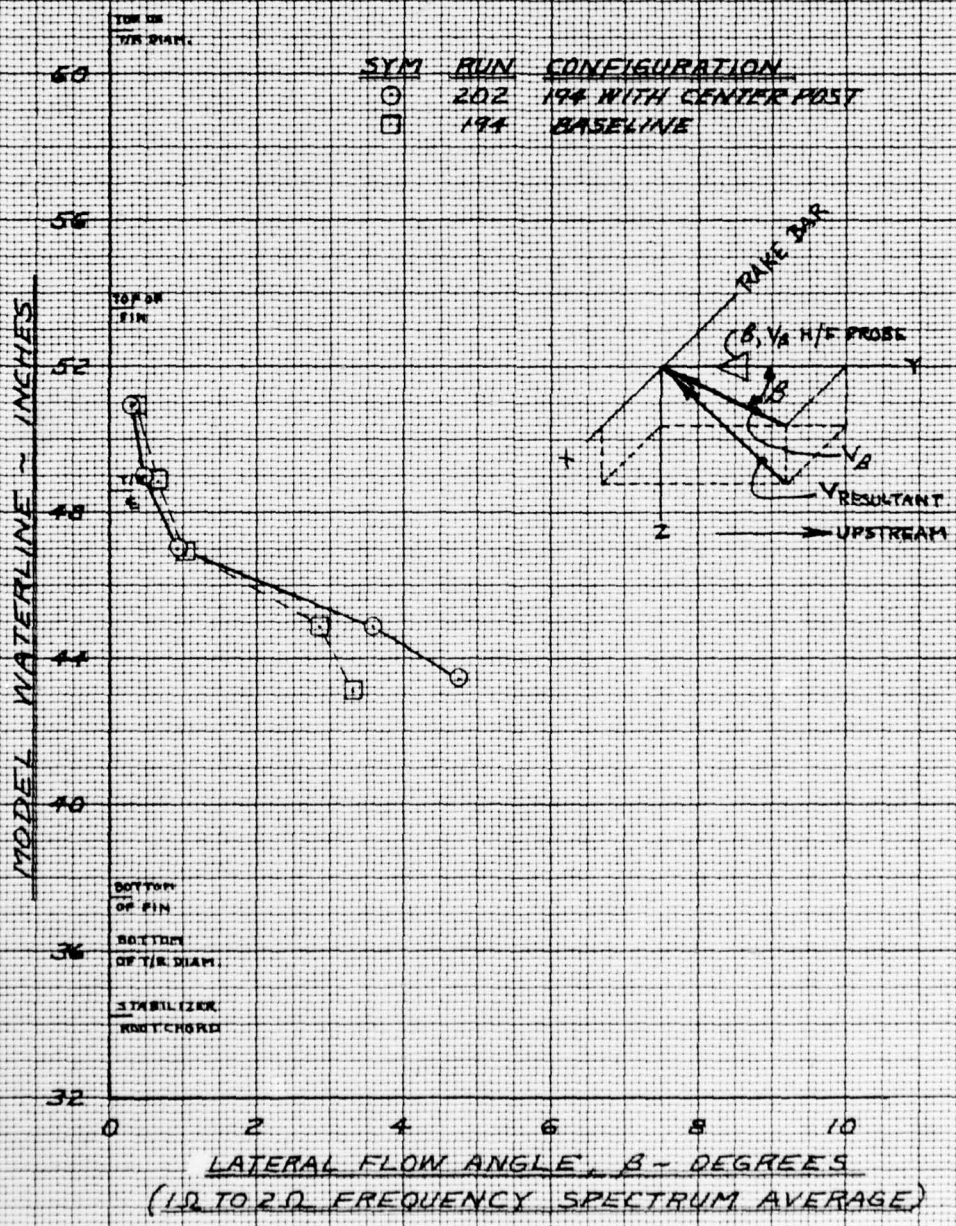
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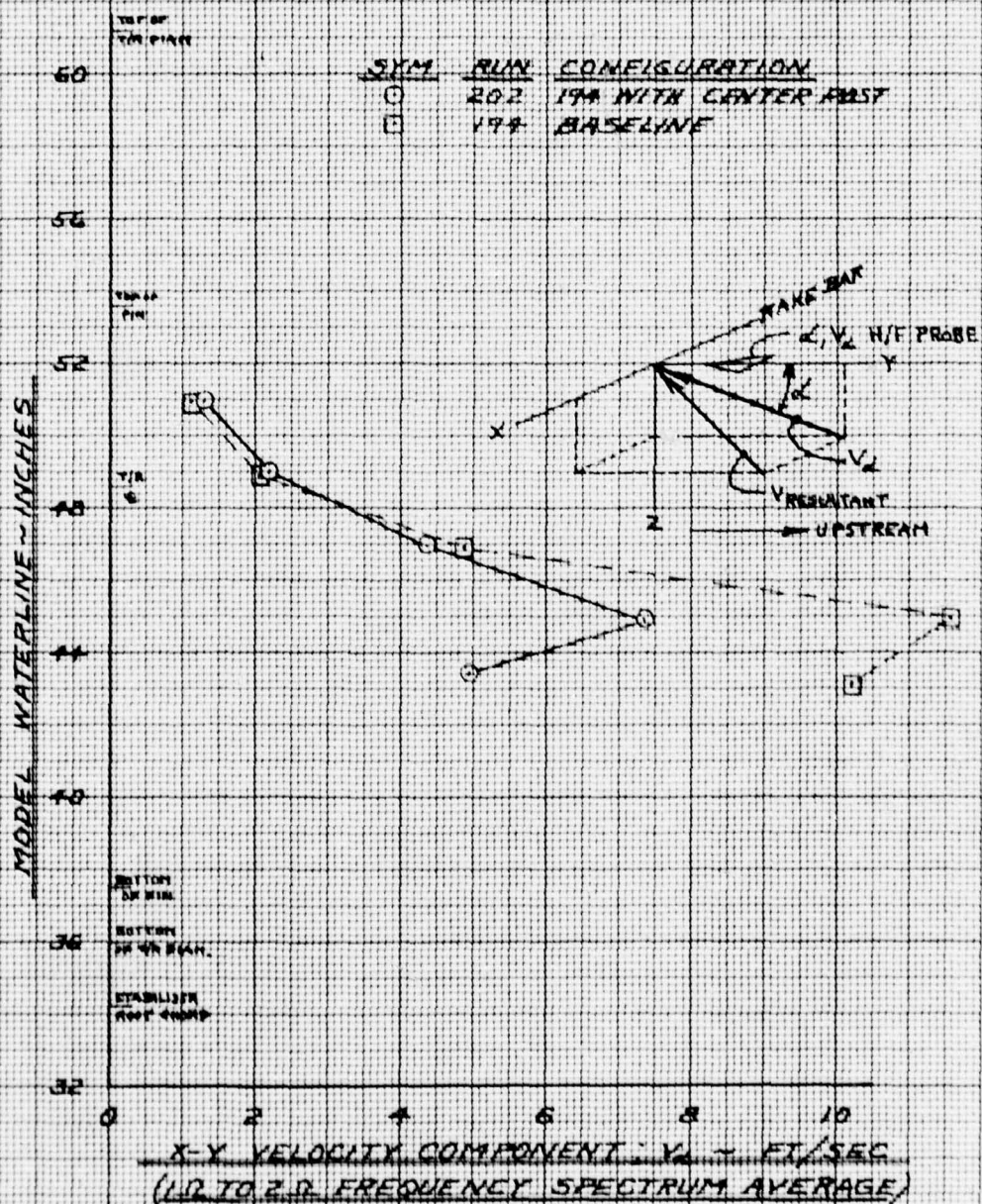
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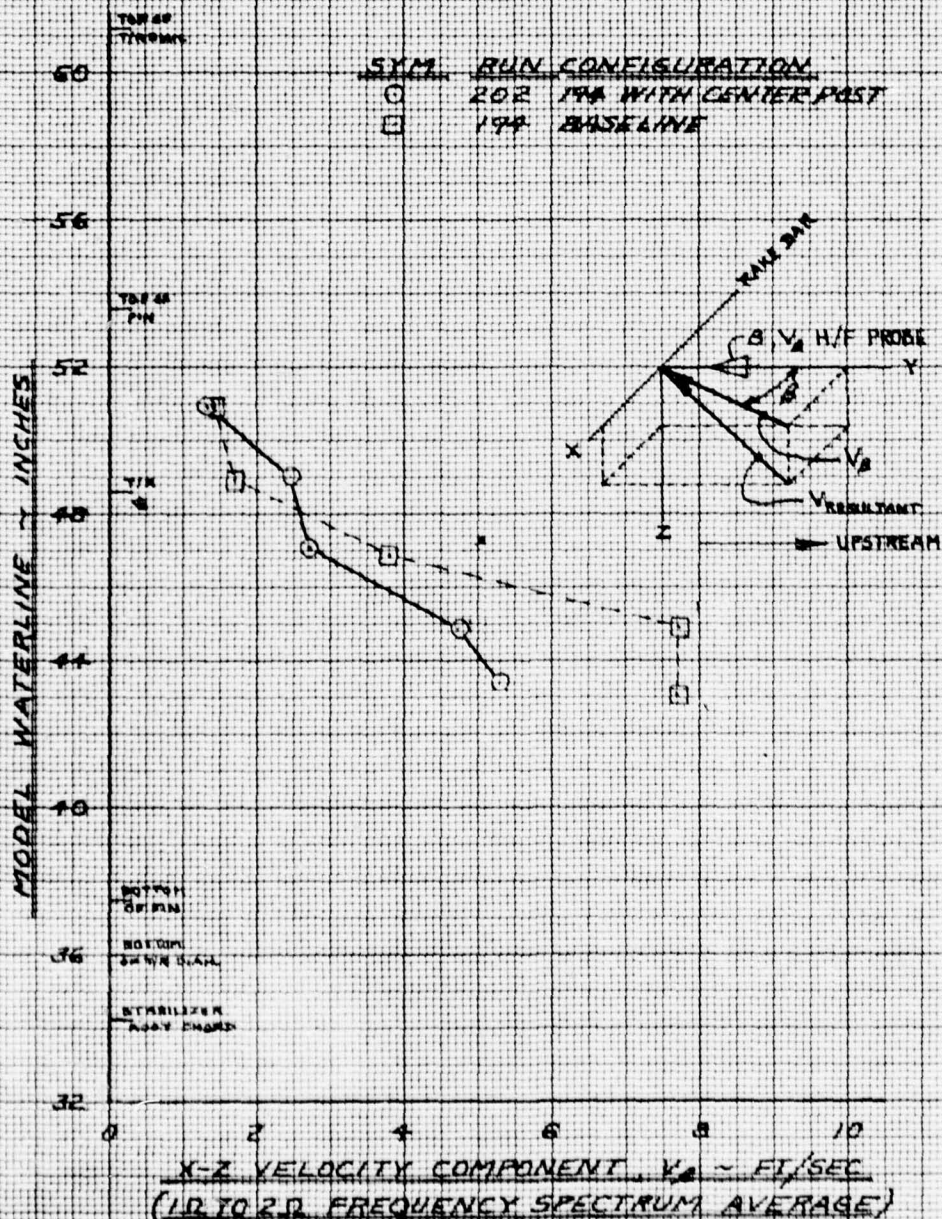
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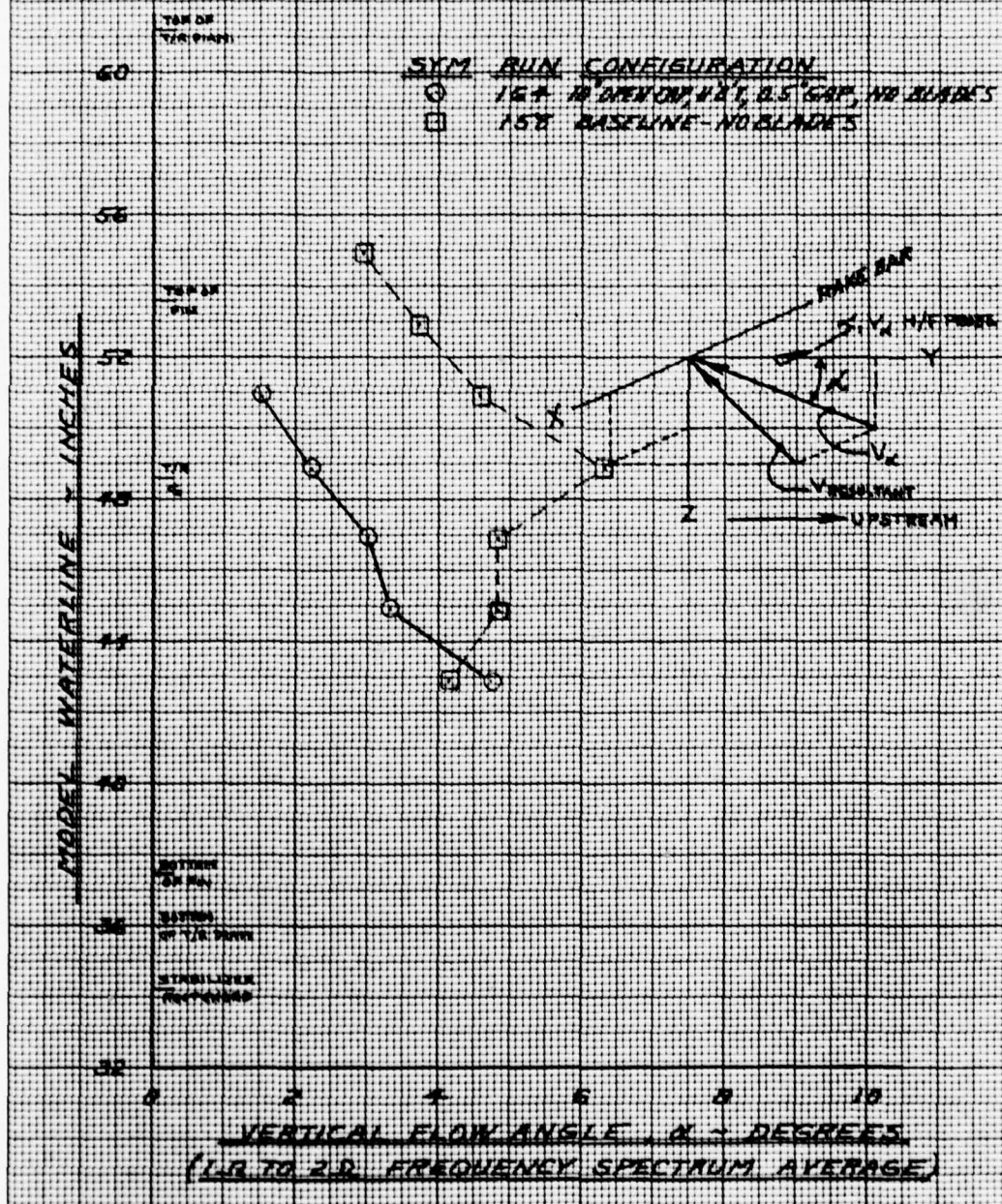
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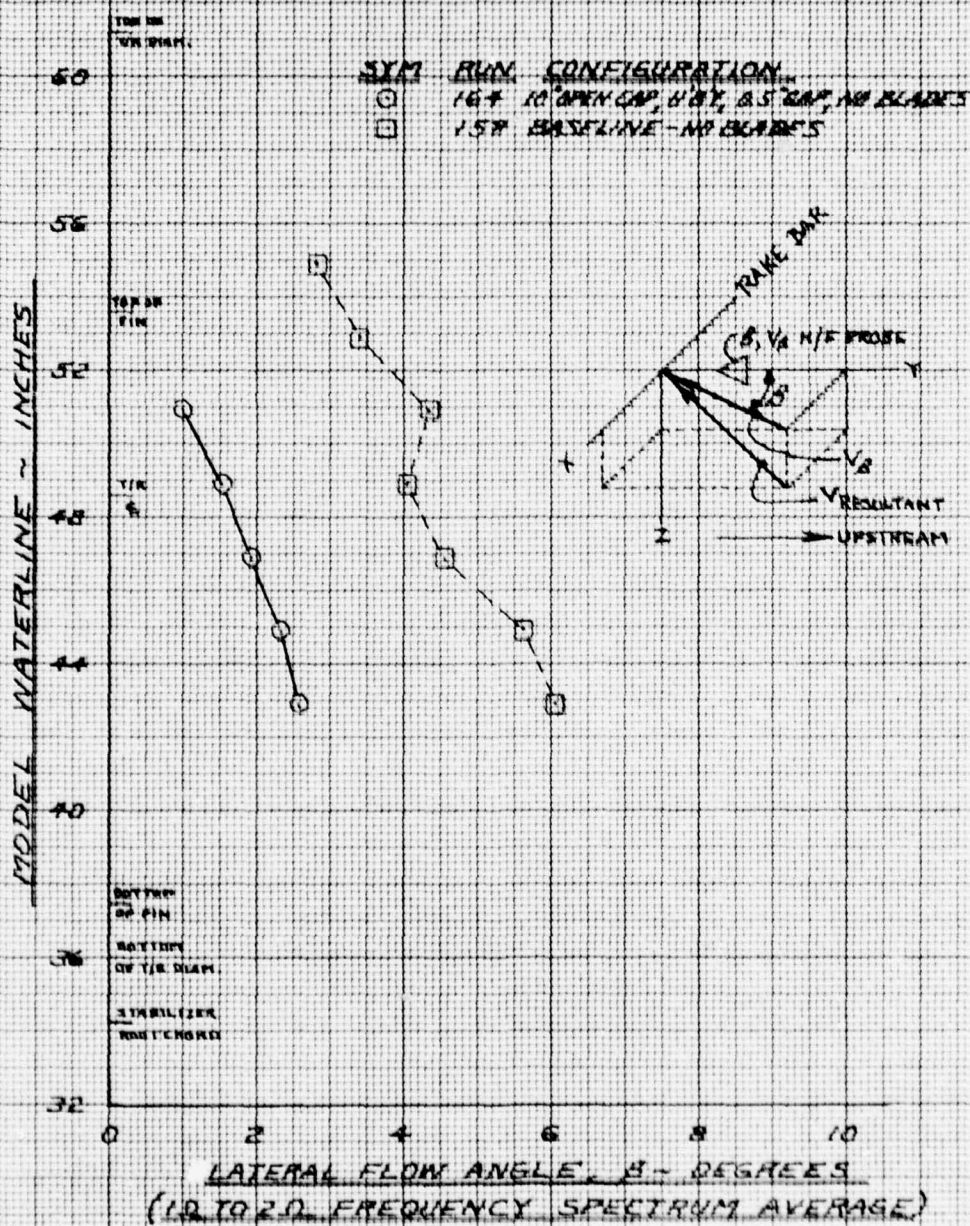
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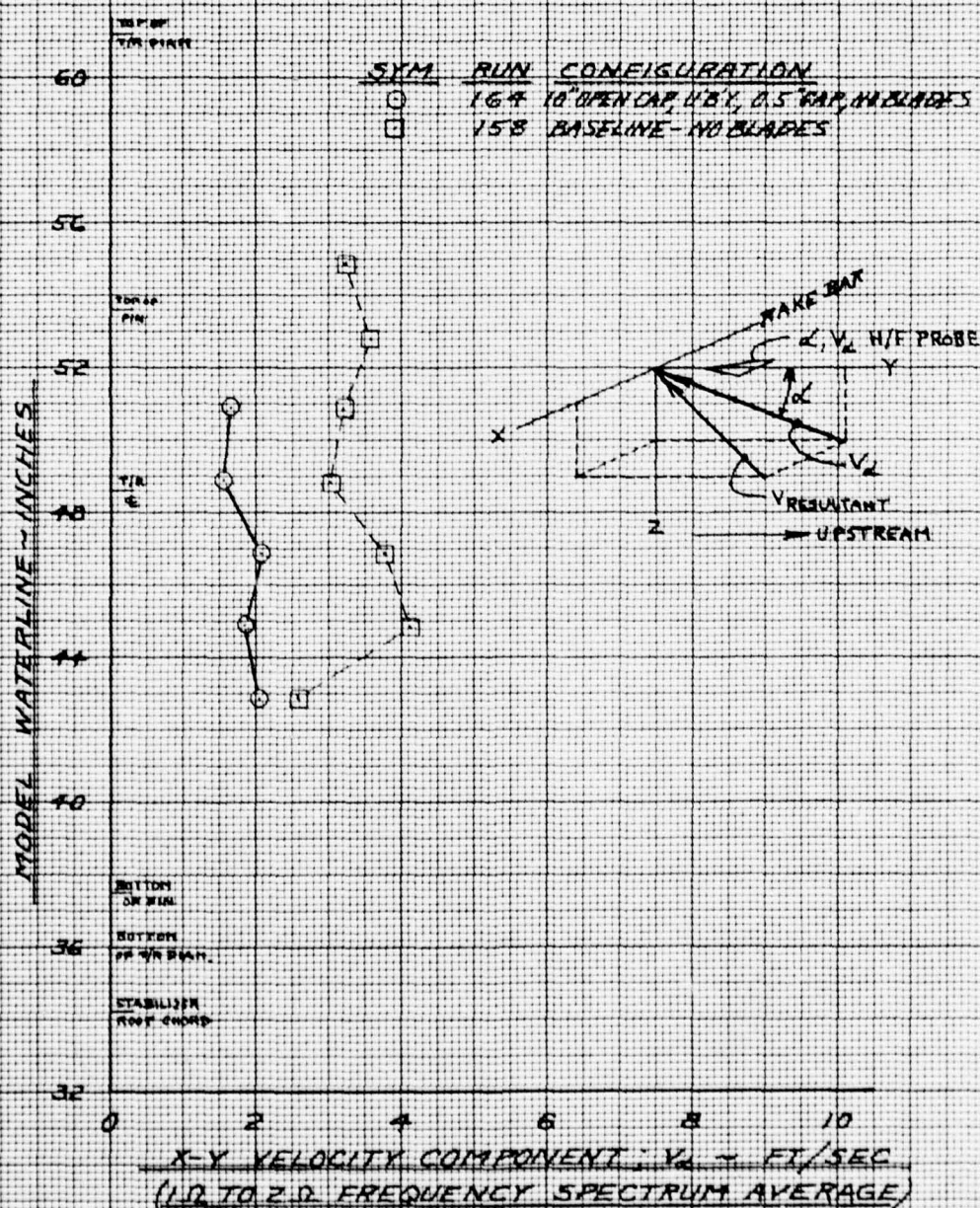
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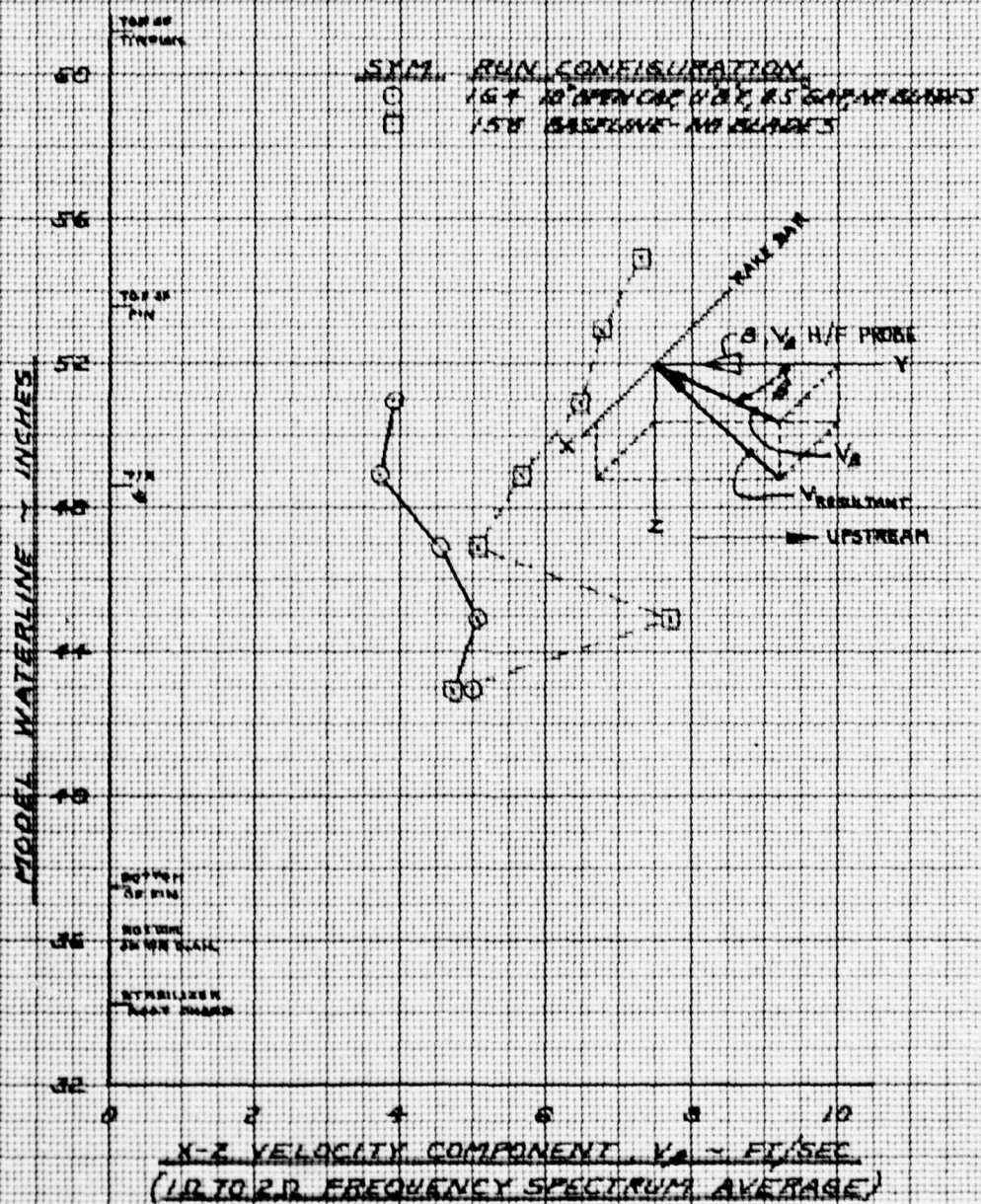
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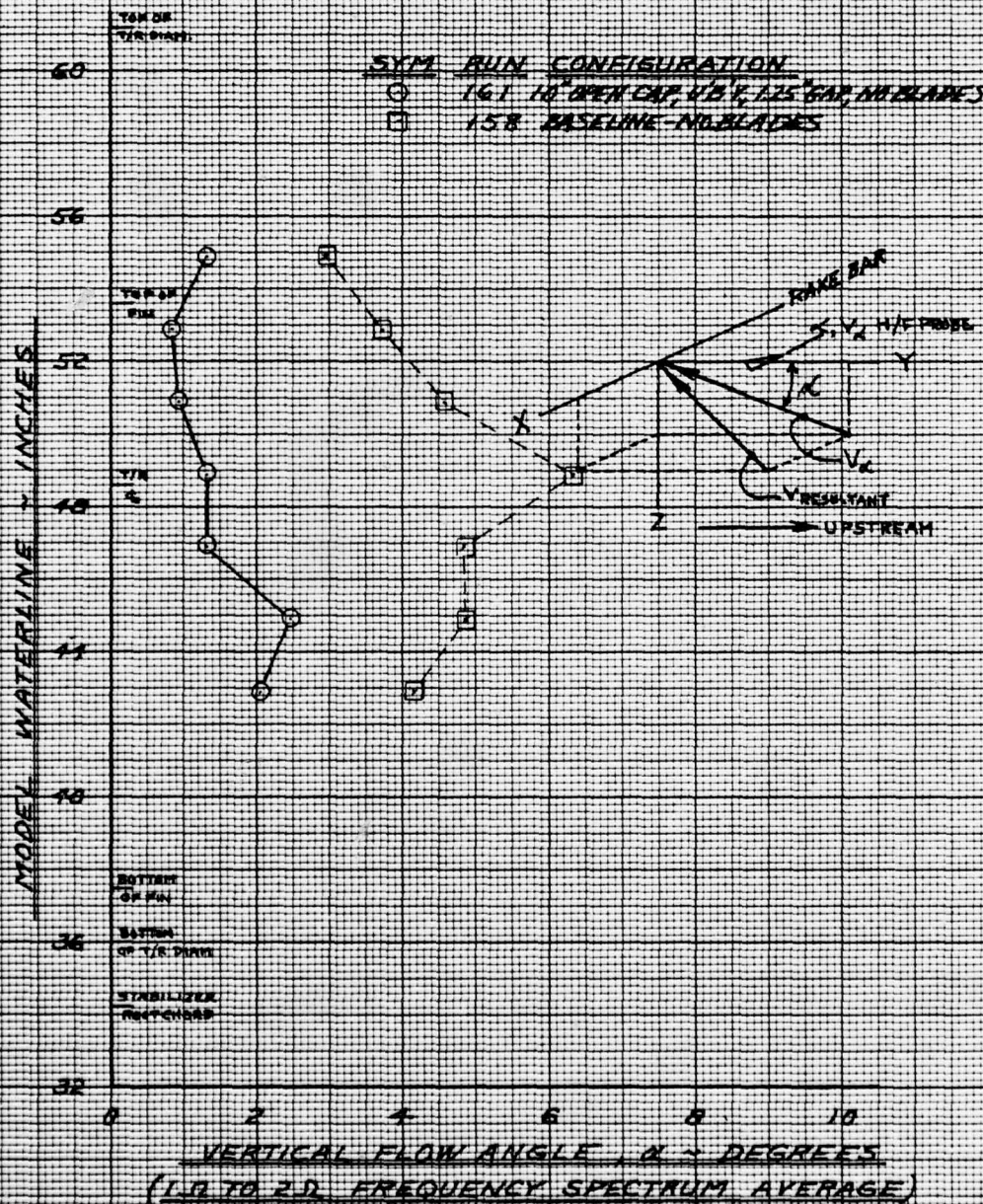
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ROTOR/HUB WAKE MODIFICATION STUDIES

UNSTEADY WAKE VERTICAL FLOW ANGLES

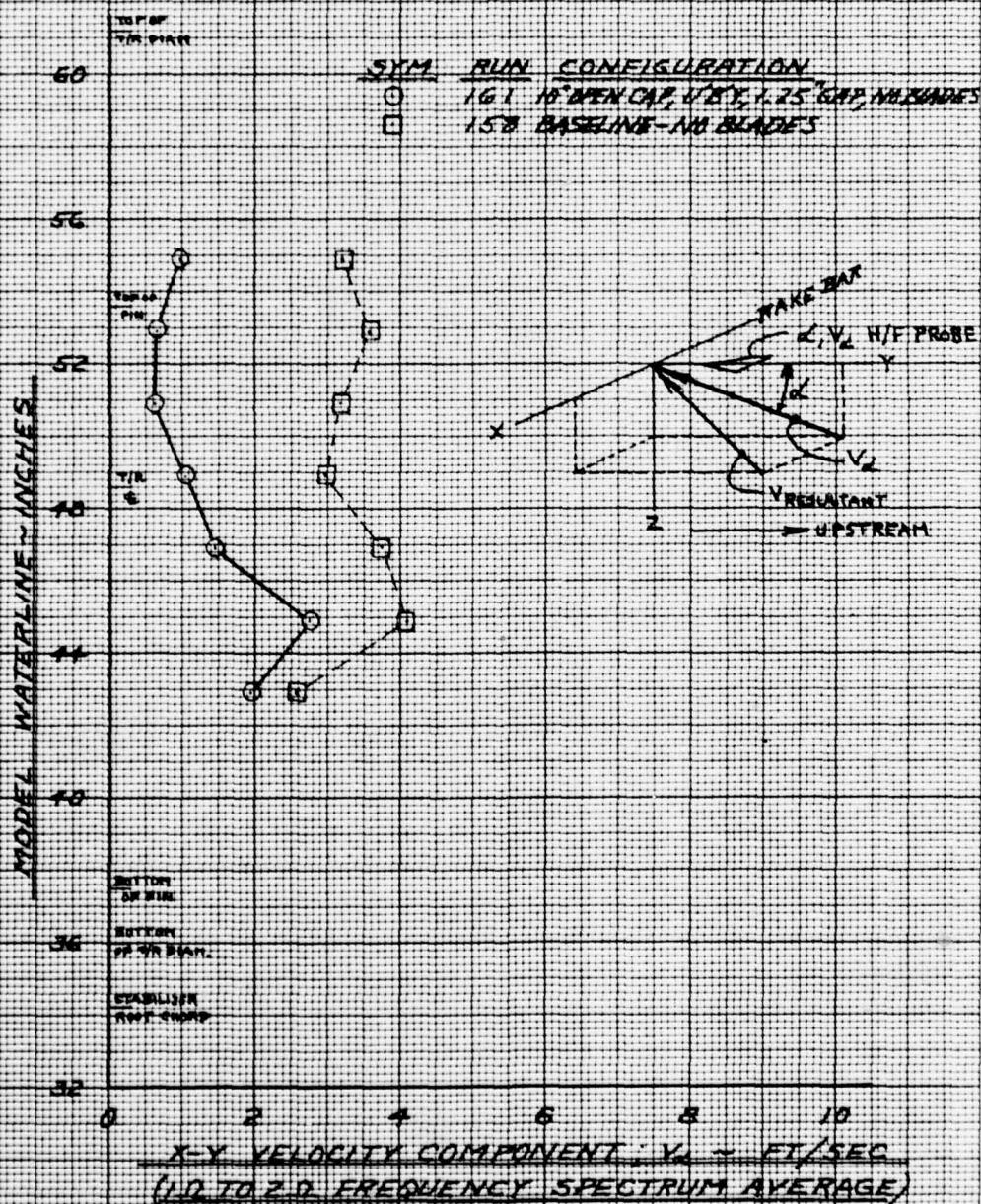


UNSTEADY WAKE LATERAL FLOW ANGLES



ROTOR/HUB WAKE MODIFICATION STUDIES

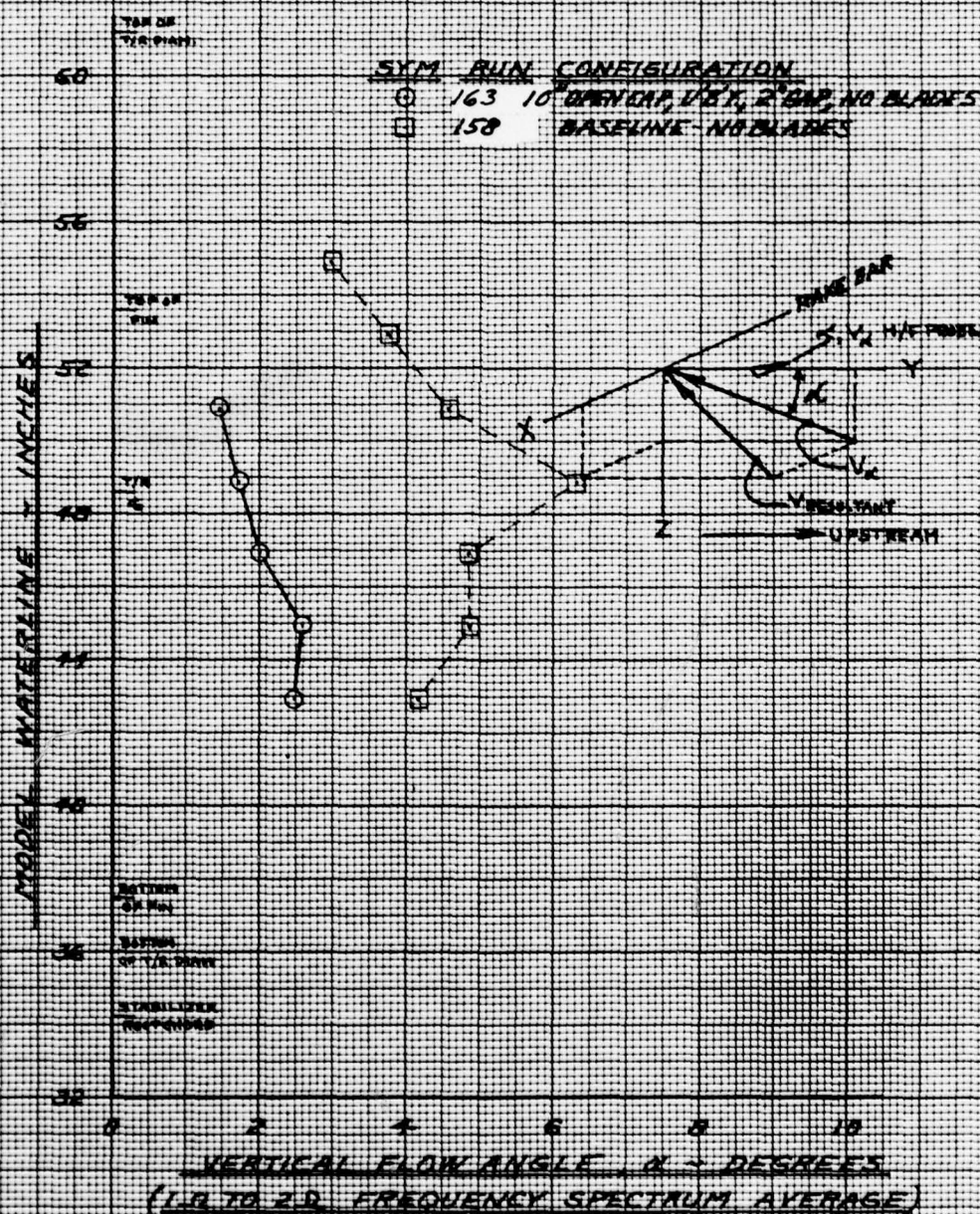
UNSTEADY WAKE X-Y VELOCITY COMPONENTS



UNSTEADY WAKE X-Z VELOCITY COMPONENTS

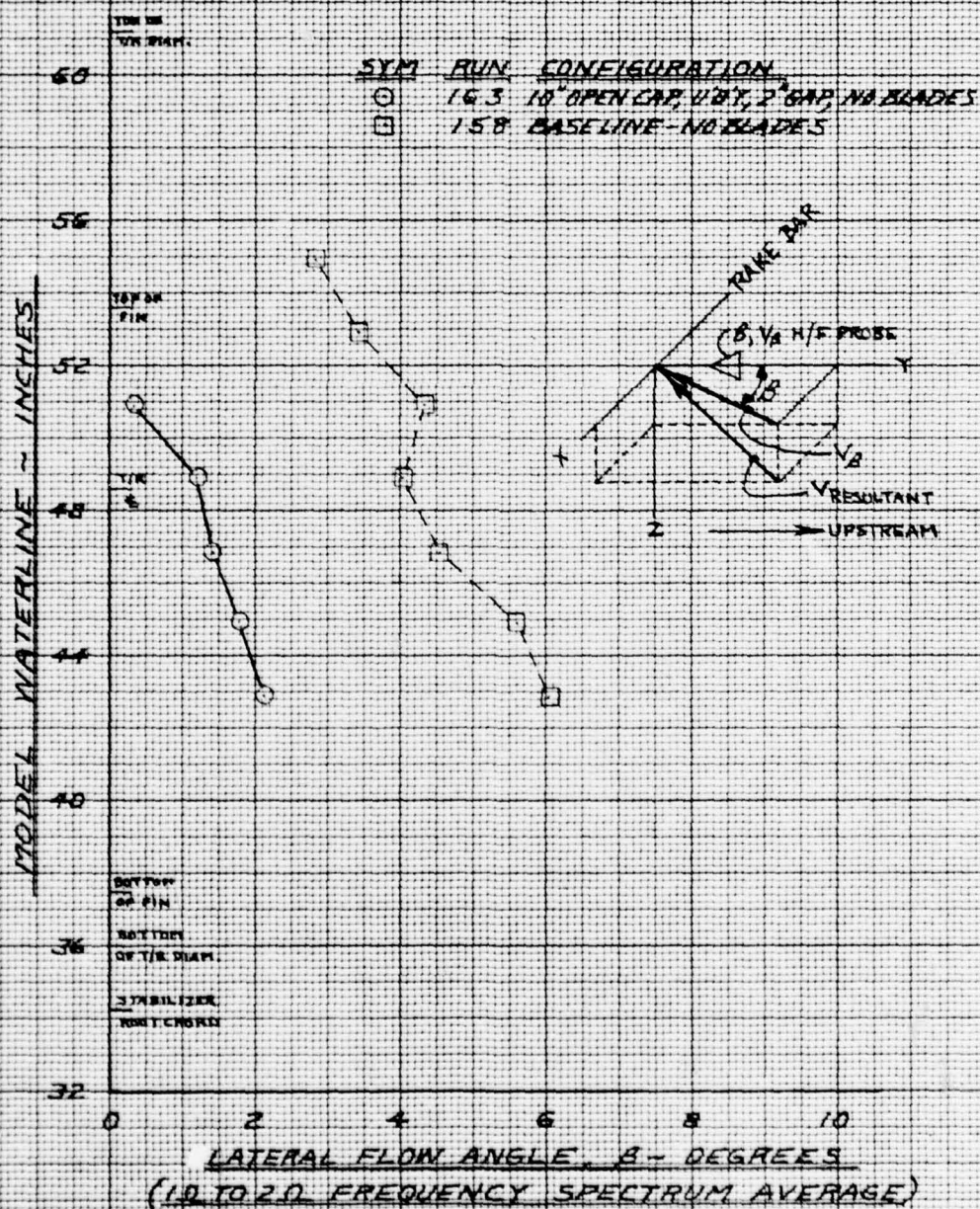


UNSTEADY WAKE VERTICAL FLOW ANGLES



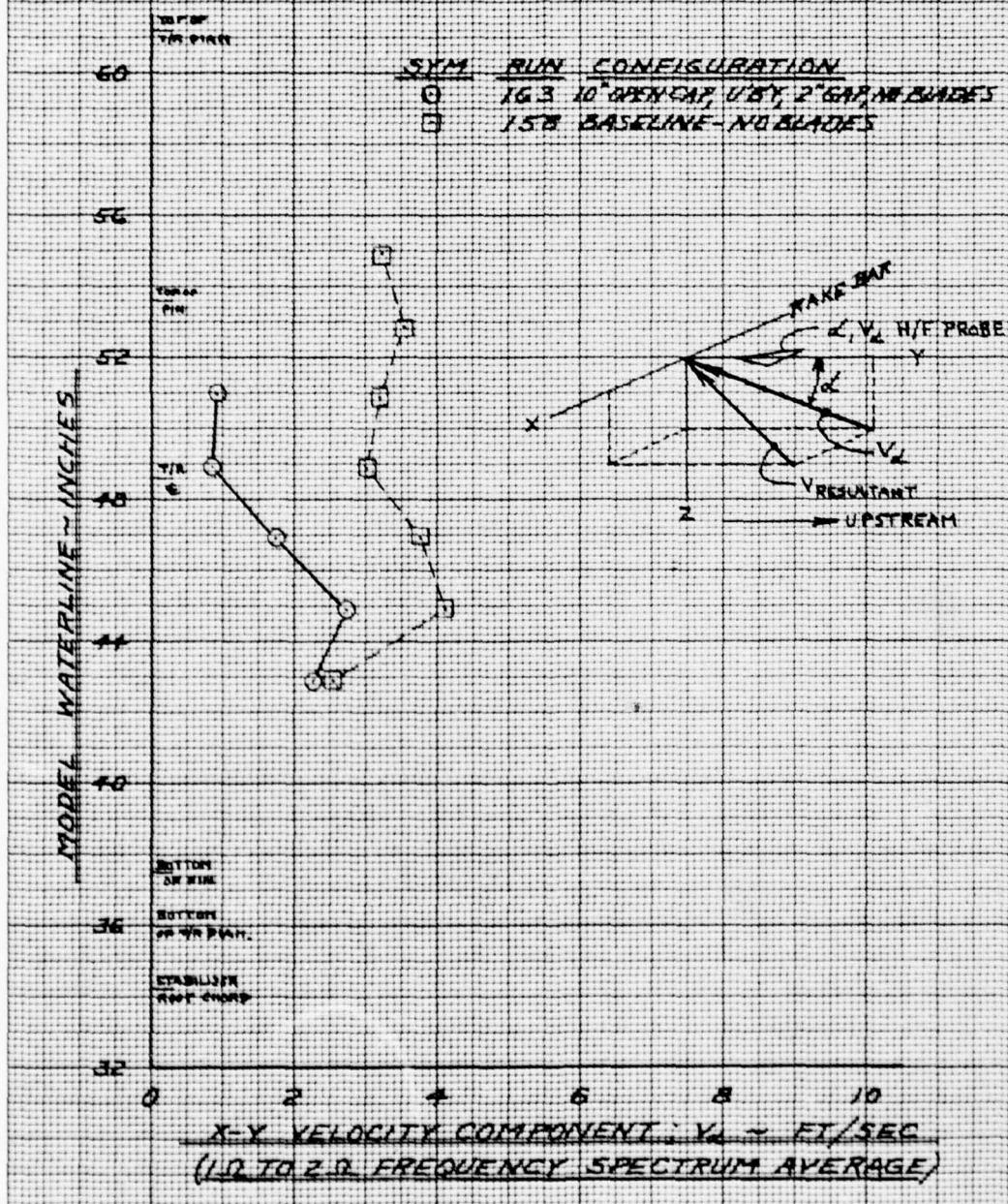
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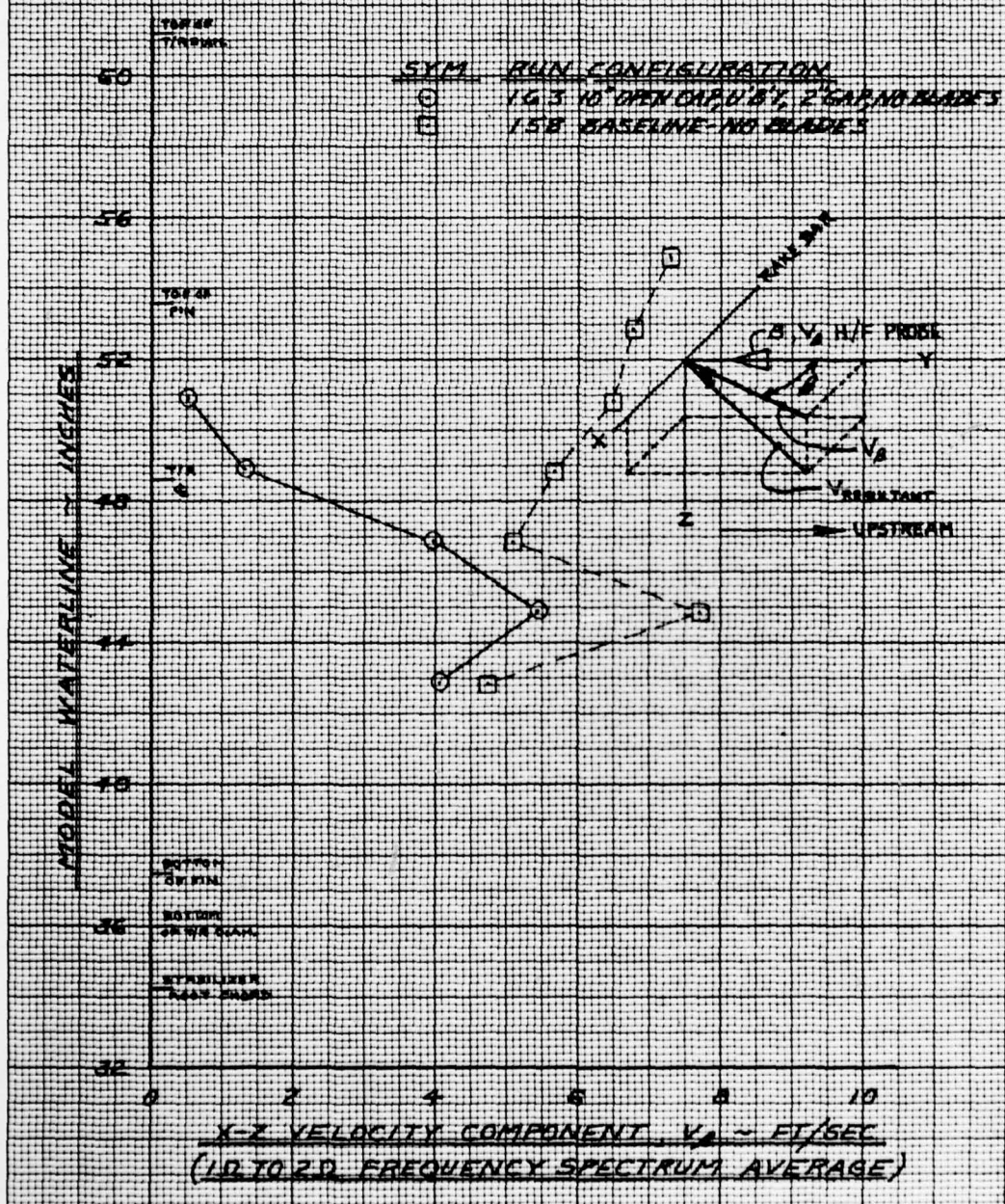
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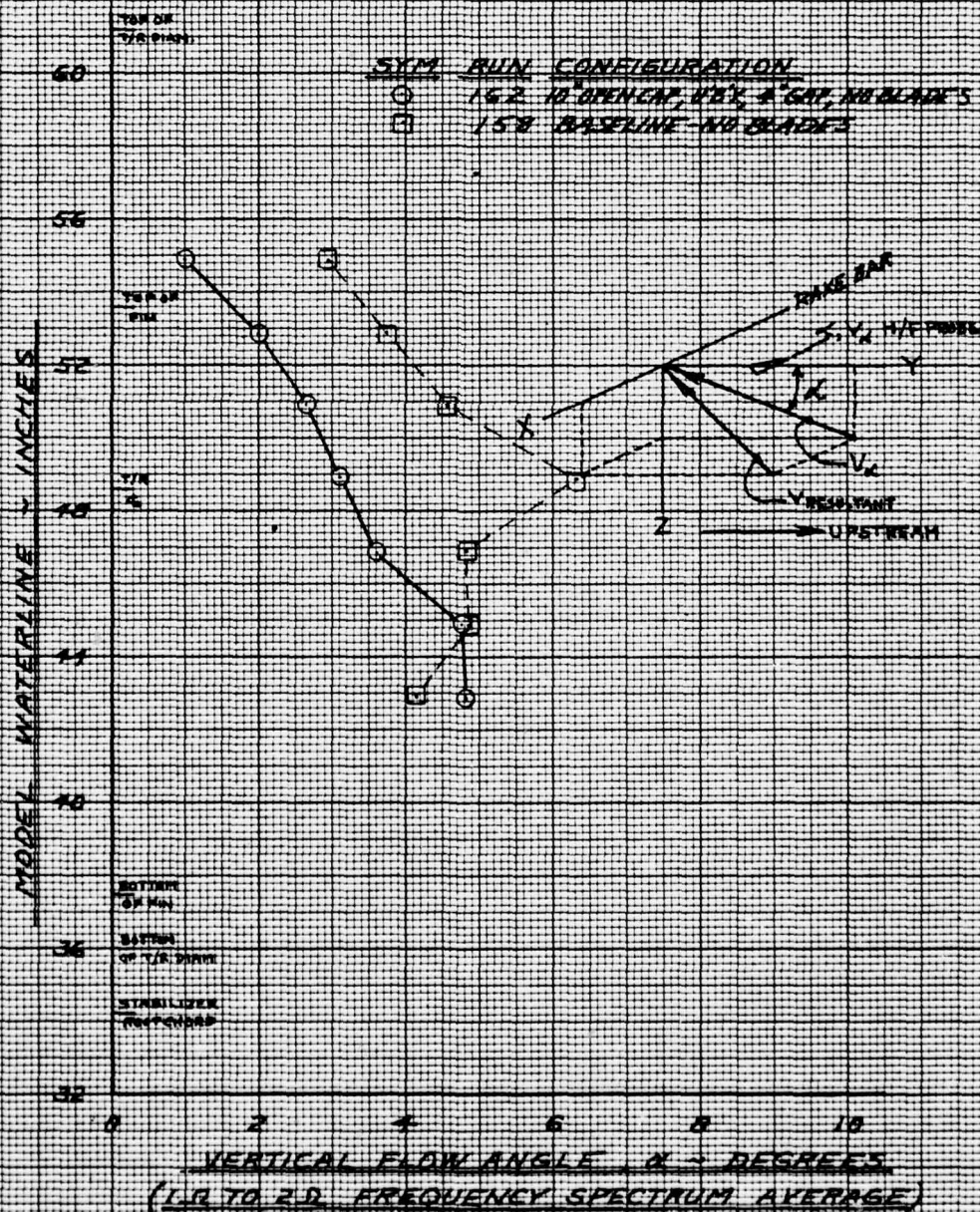
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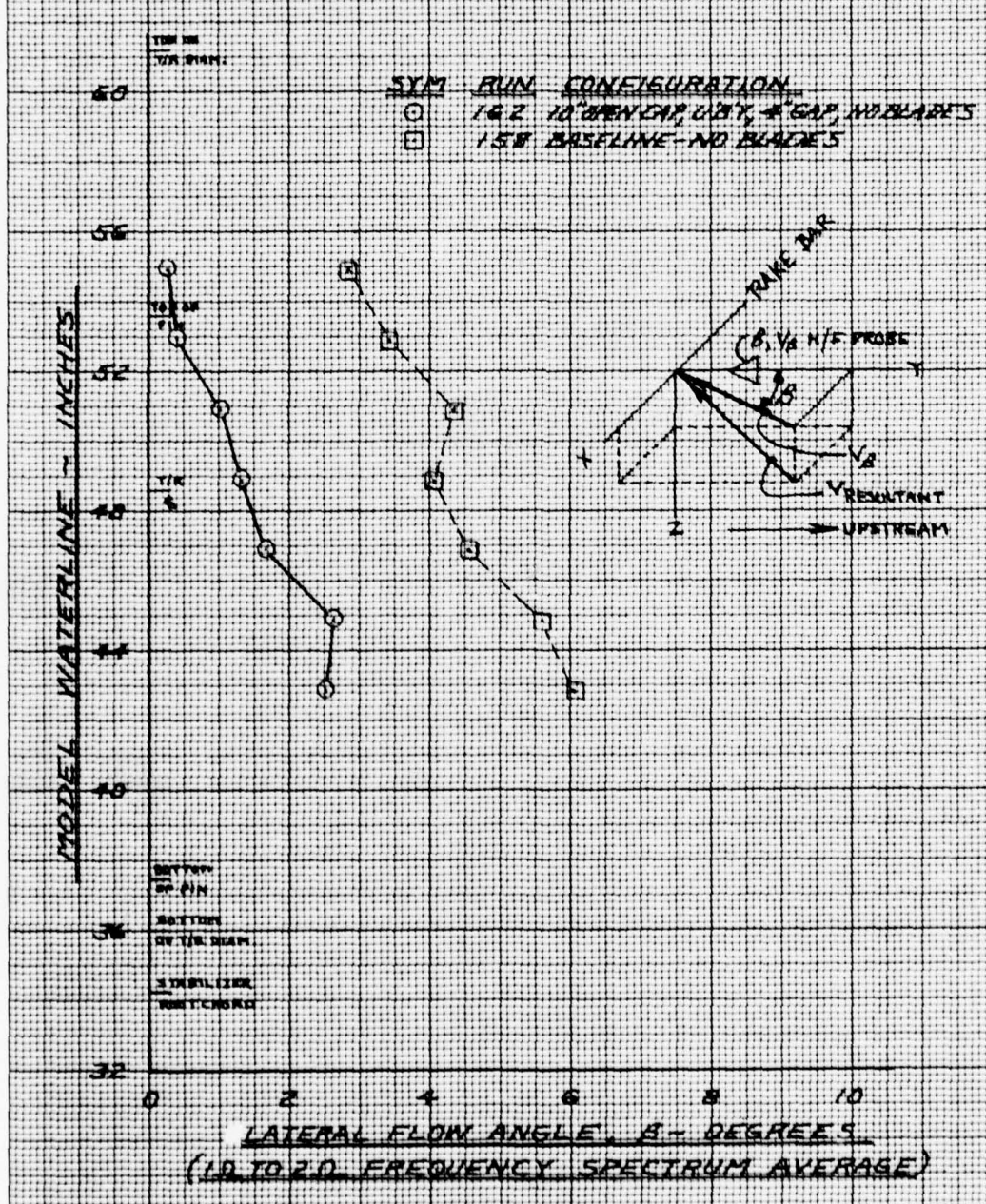
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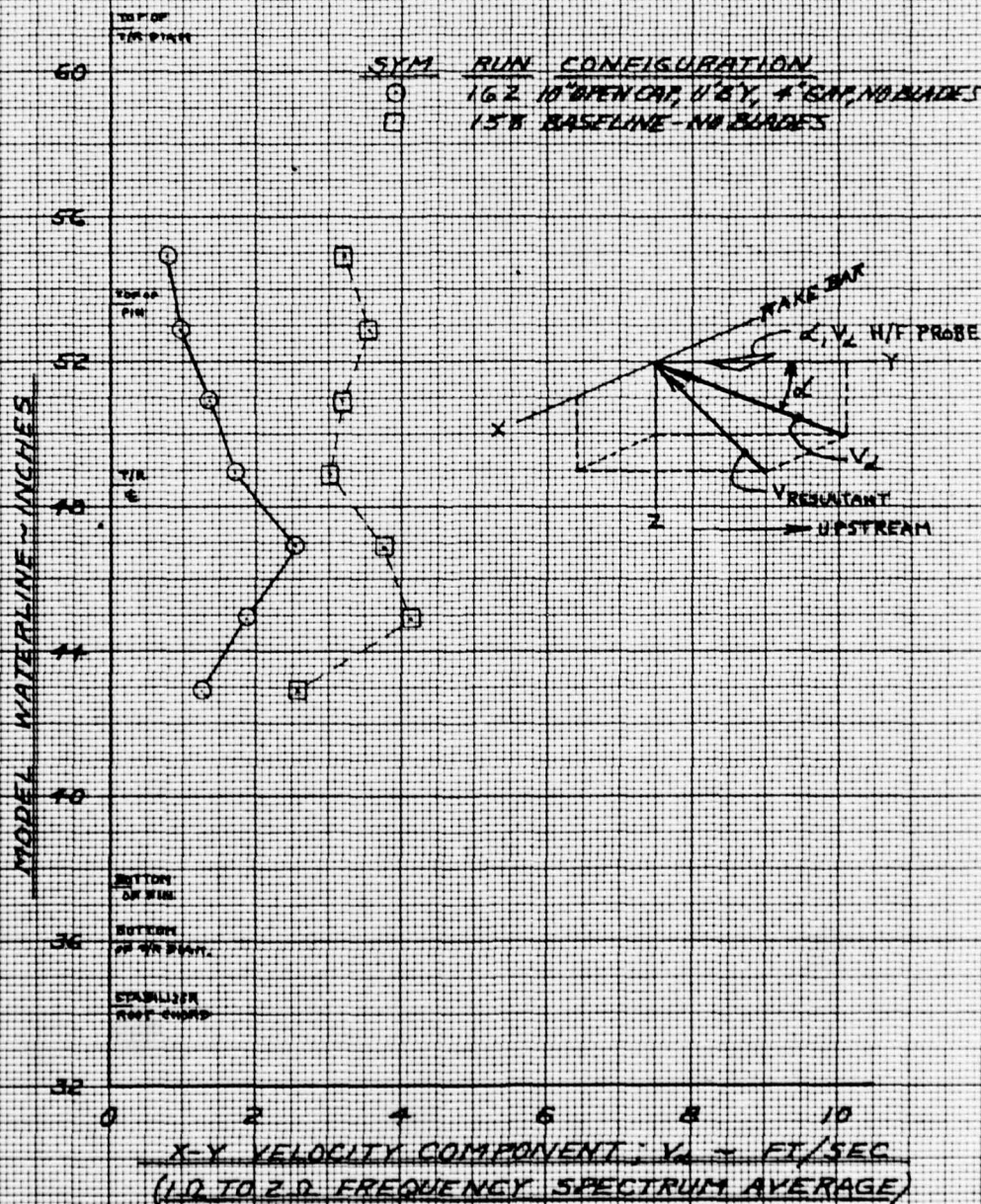
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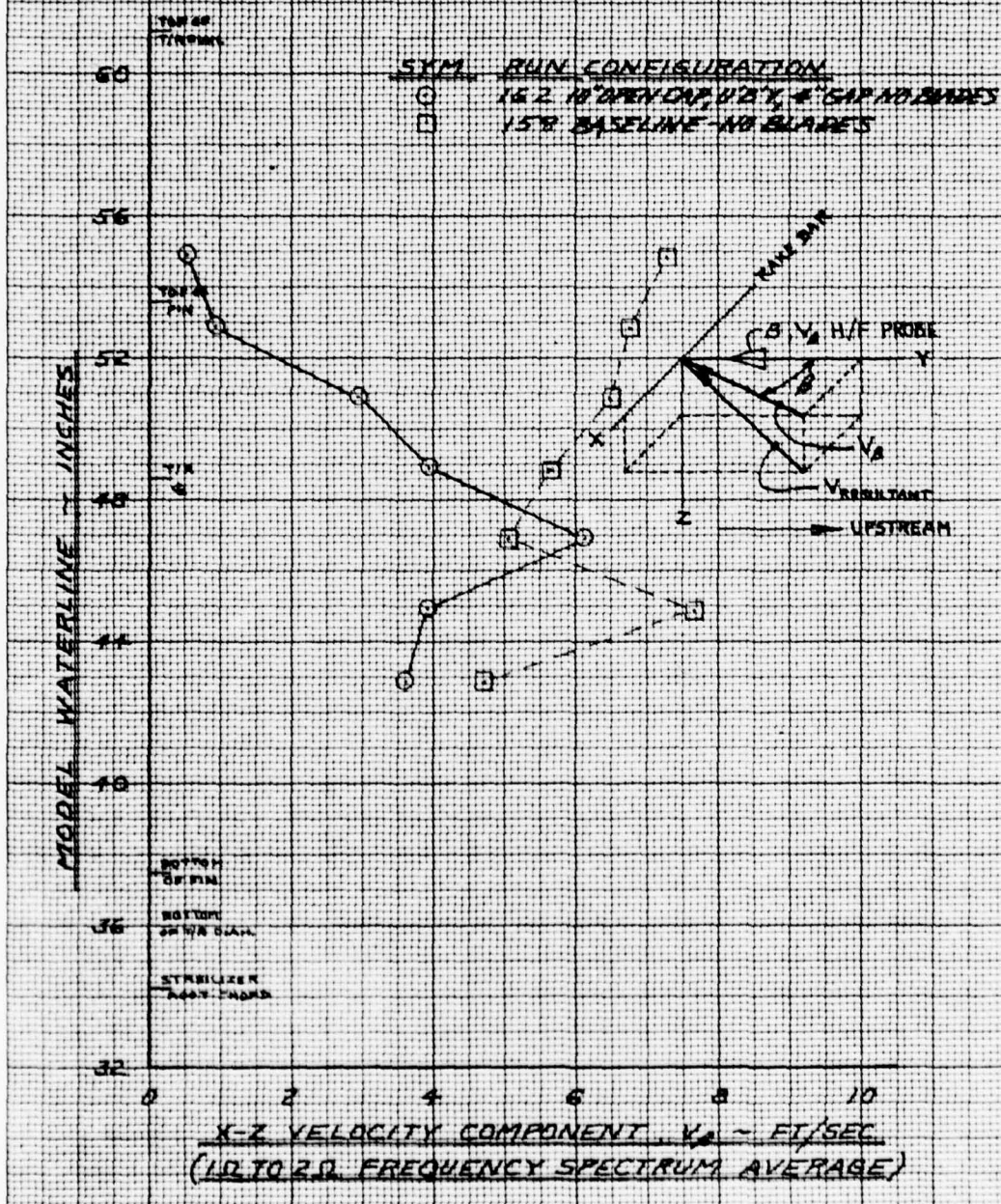
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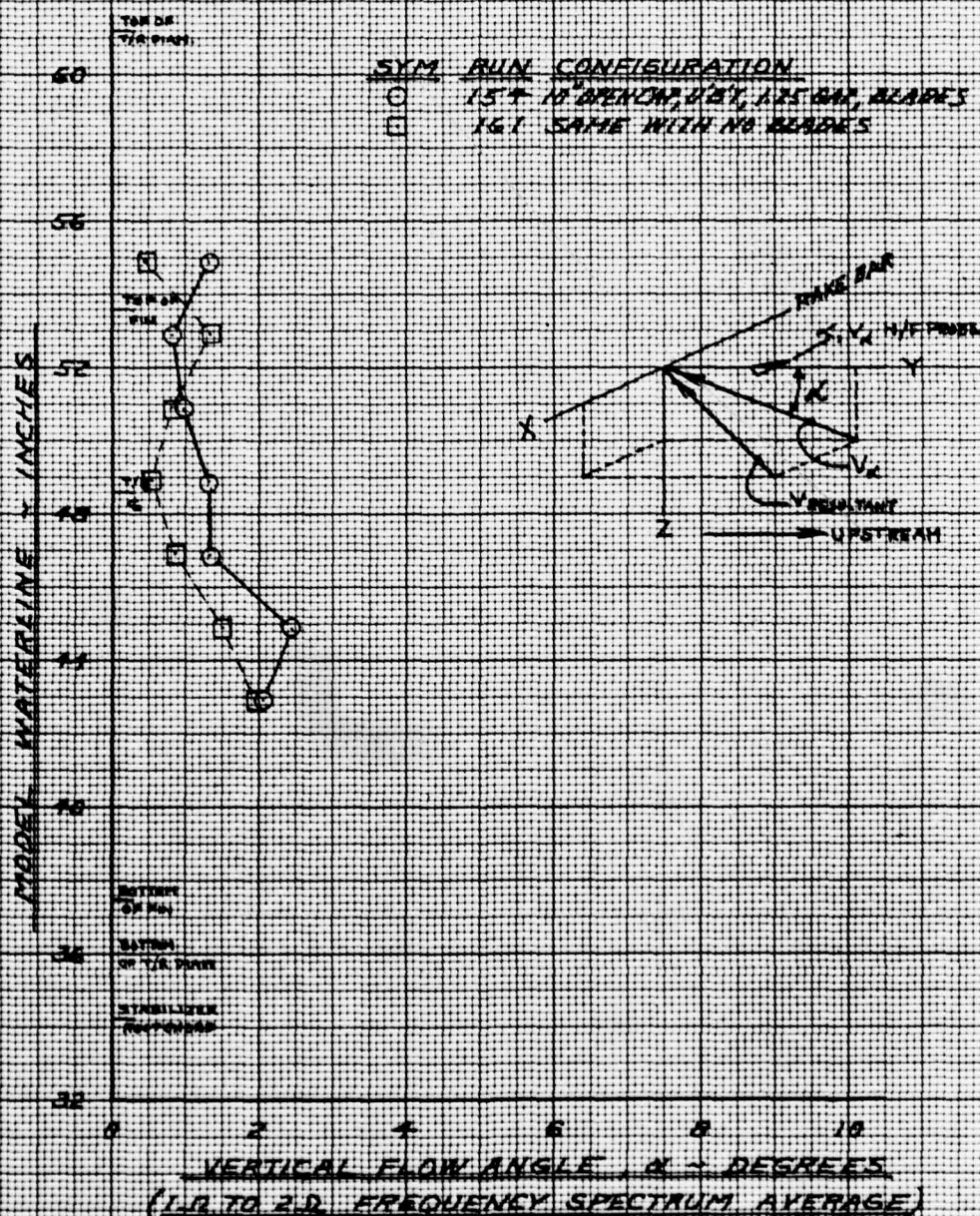
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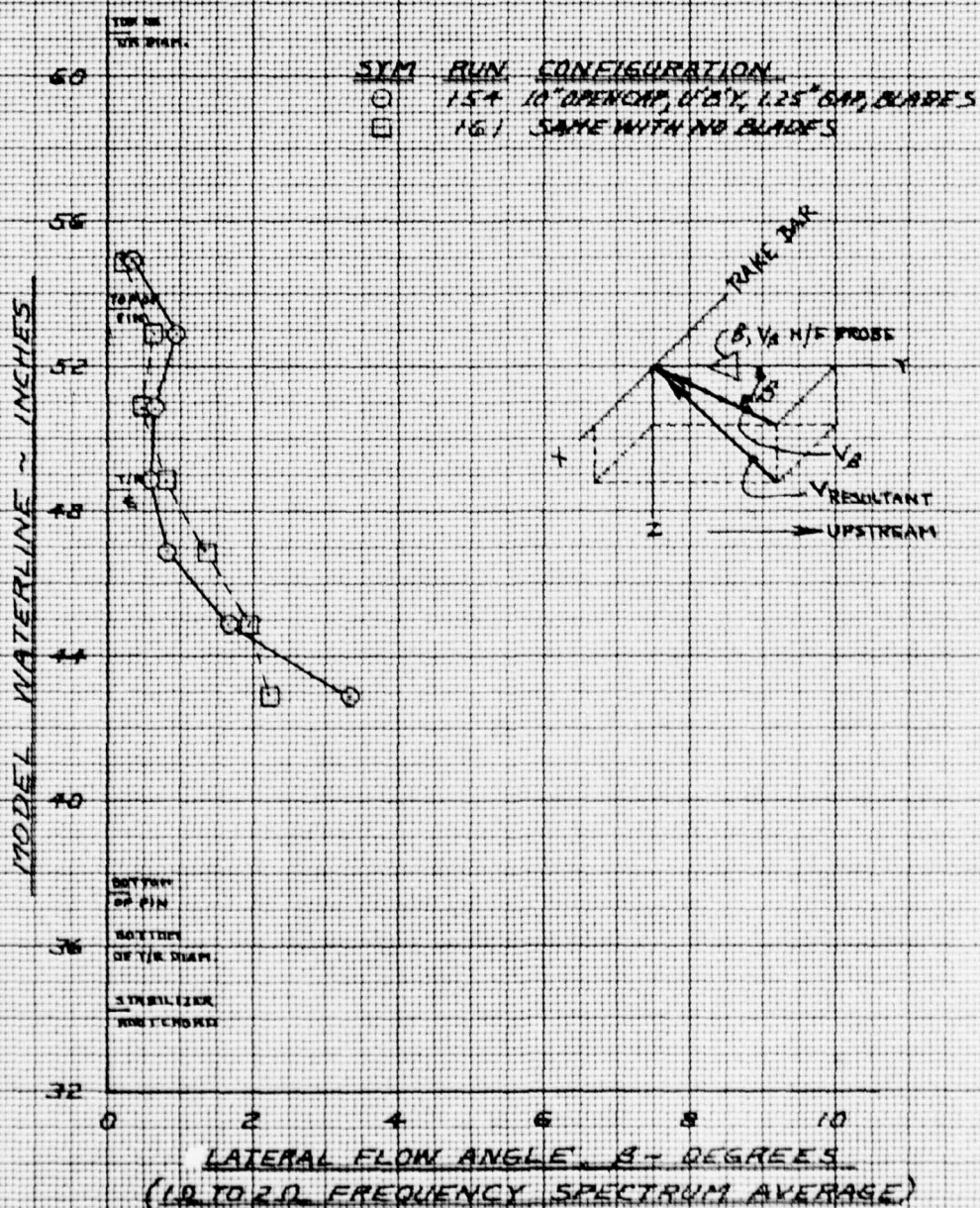
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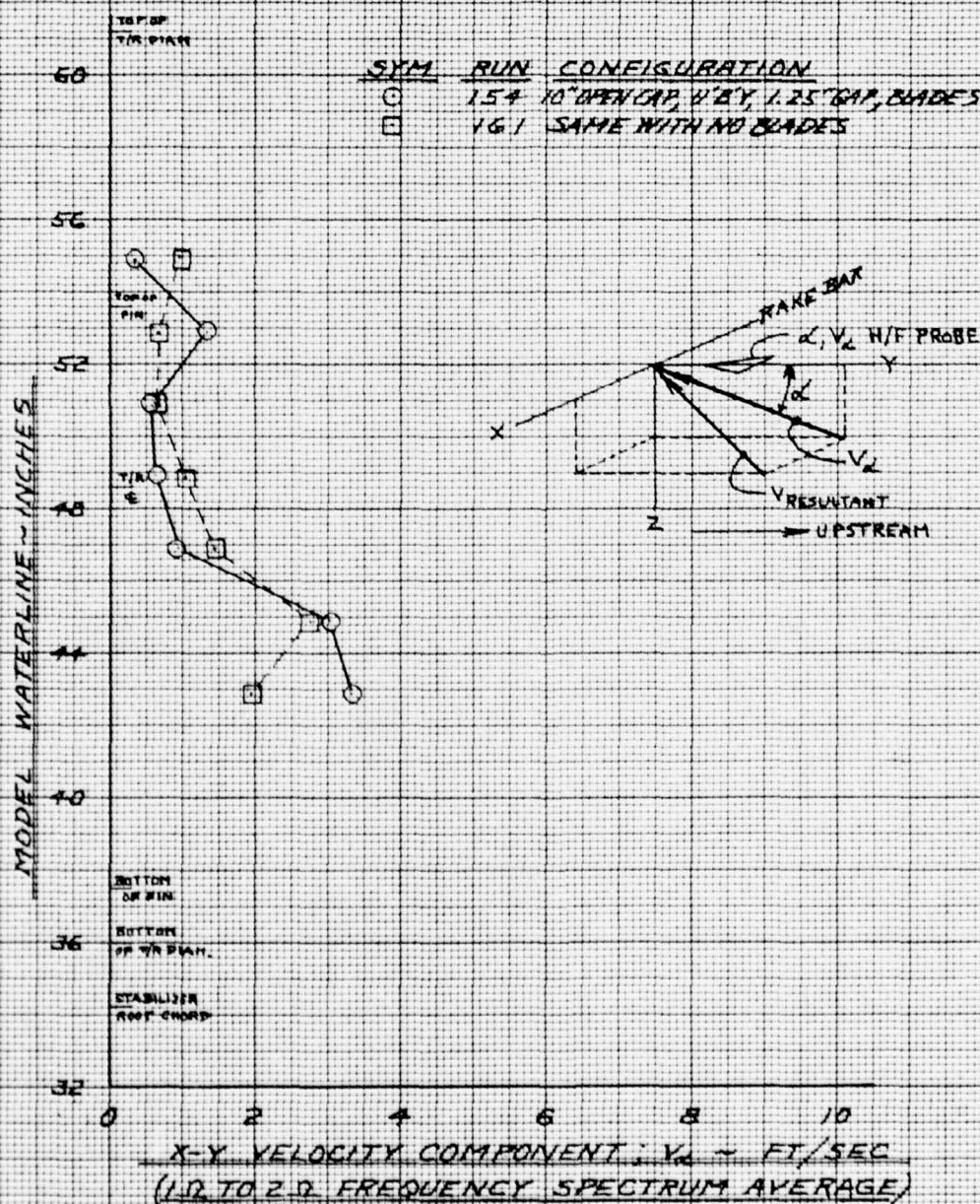
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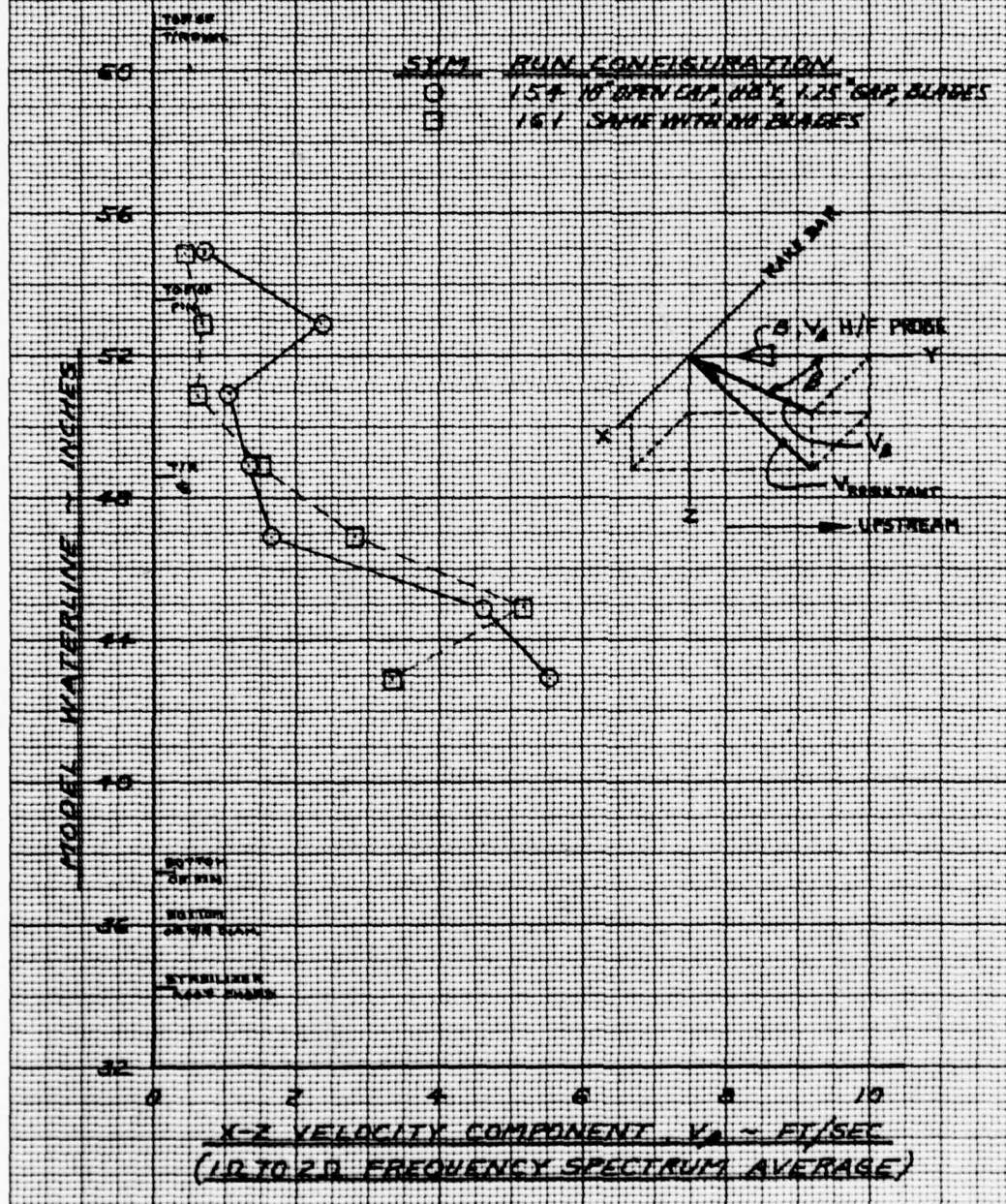
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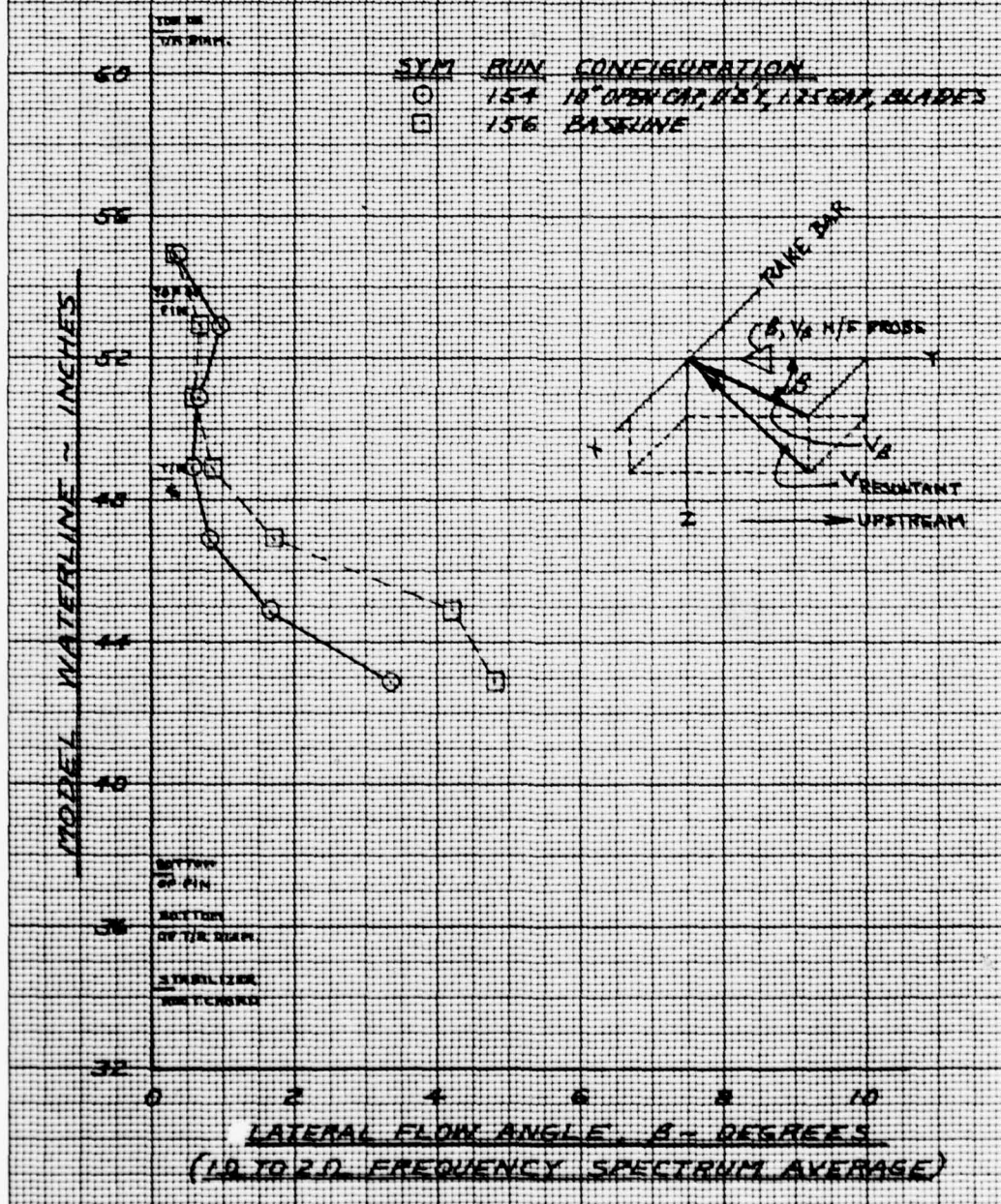
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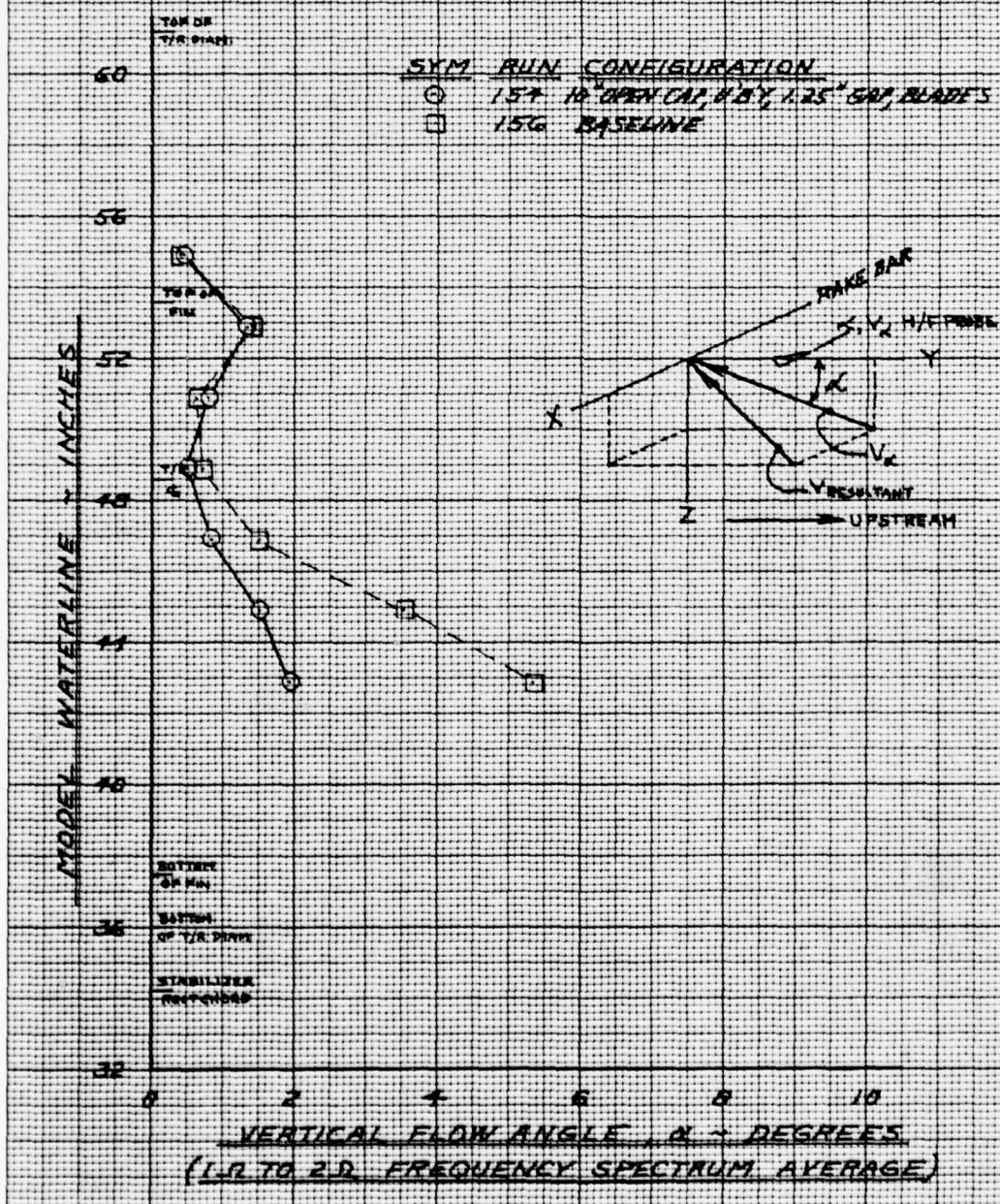
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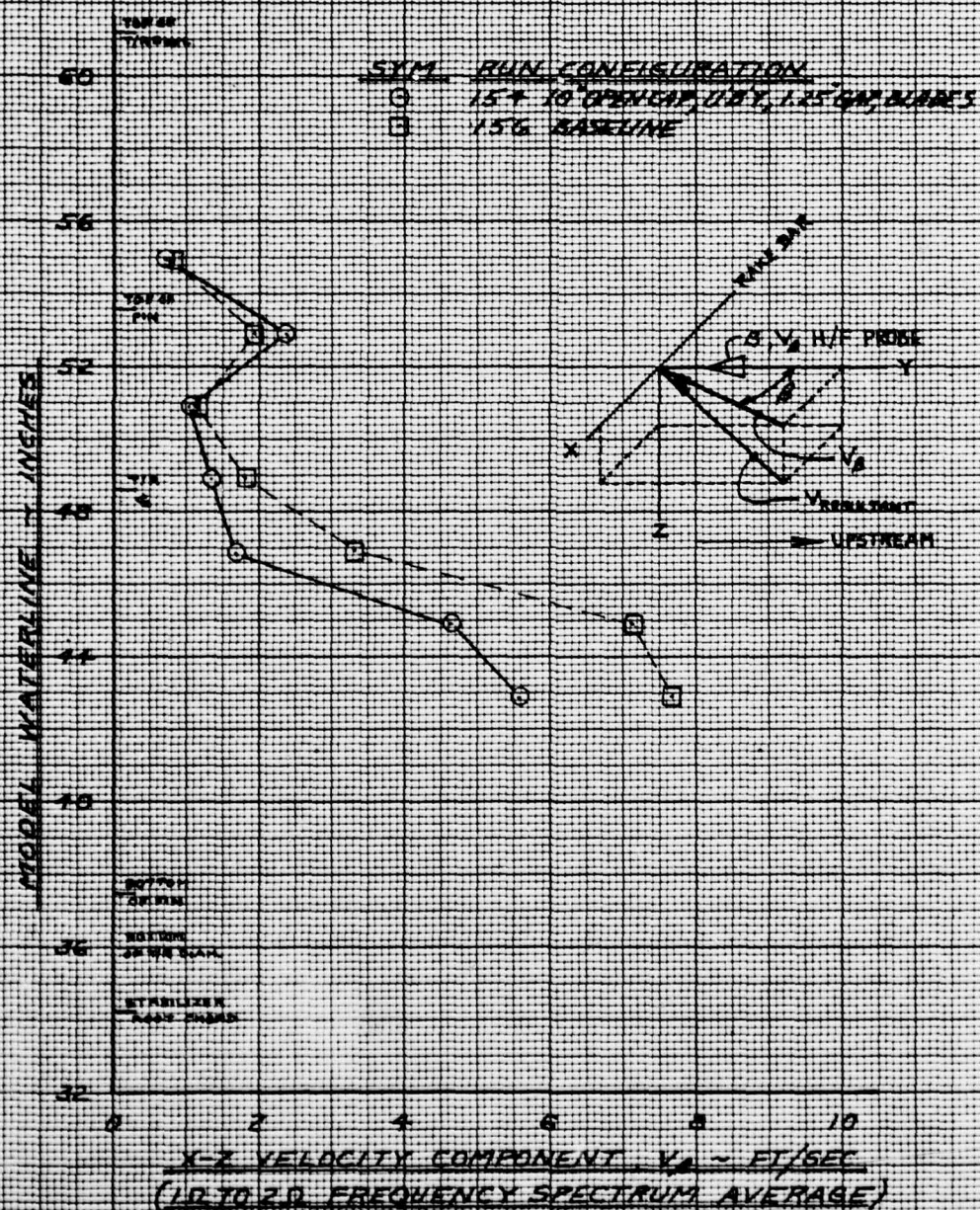


UNSTEADY WAKE X-Y VELOCITY COMPONENTS



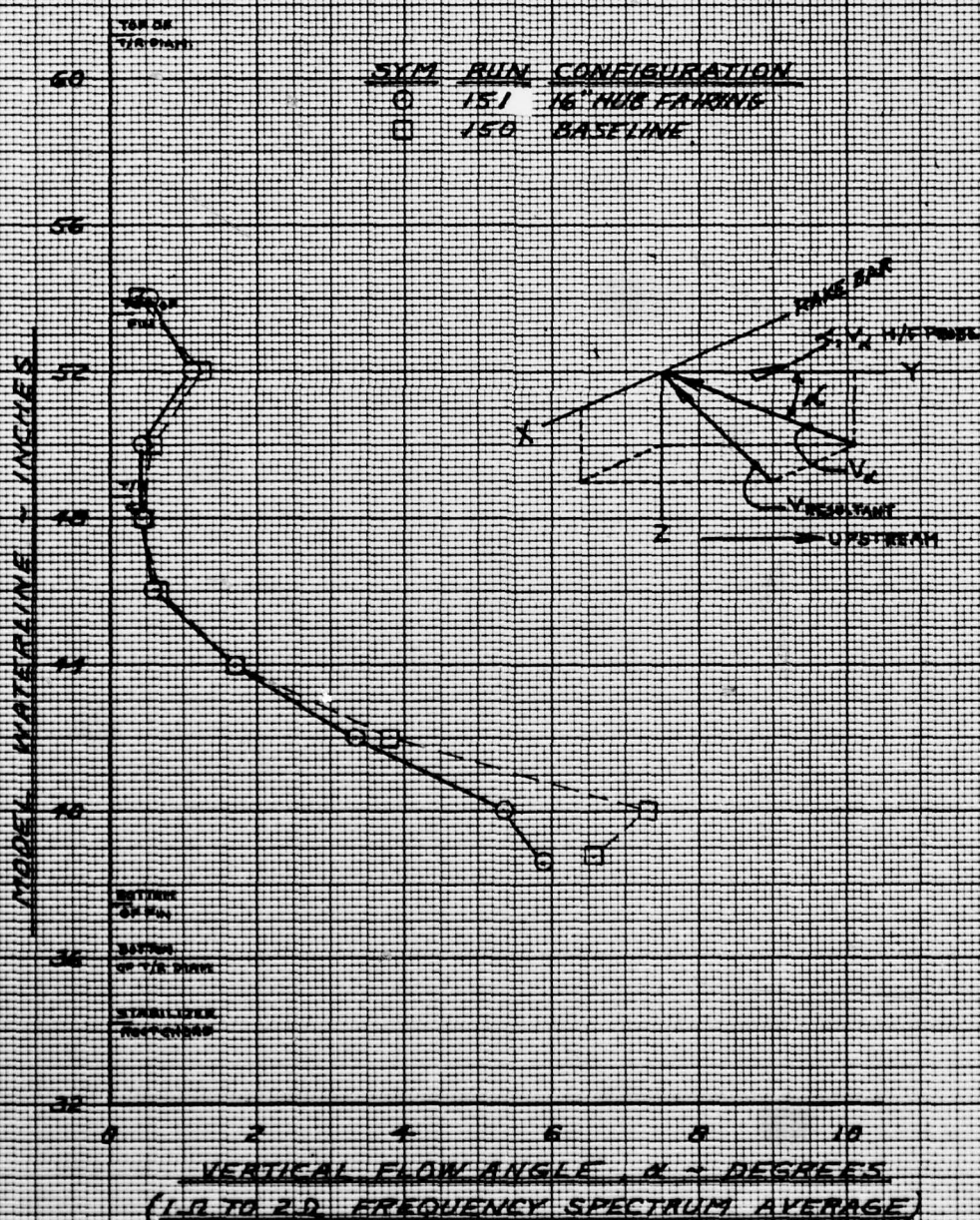
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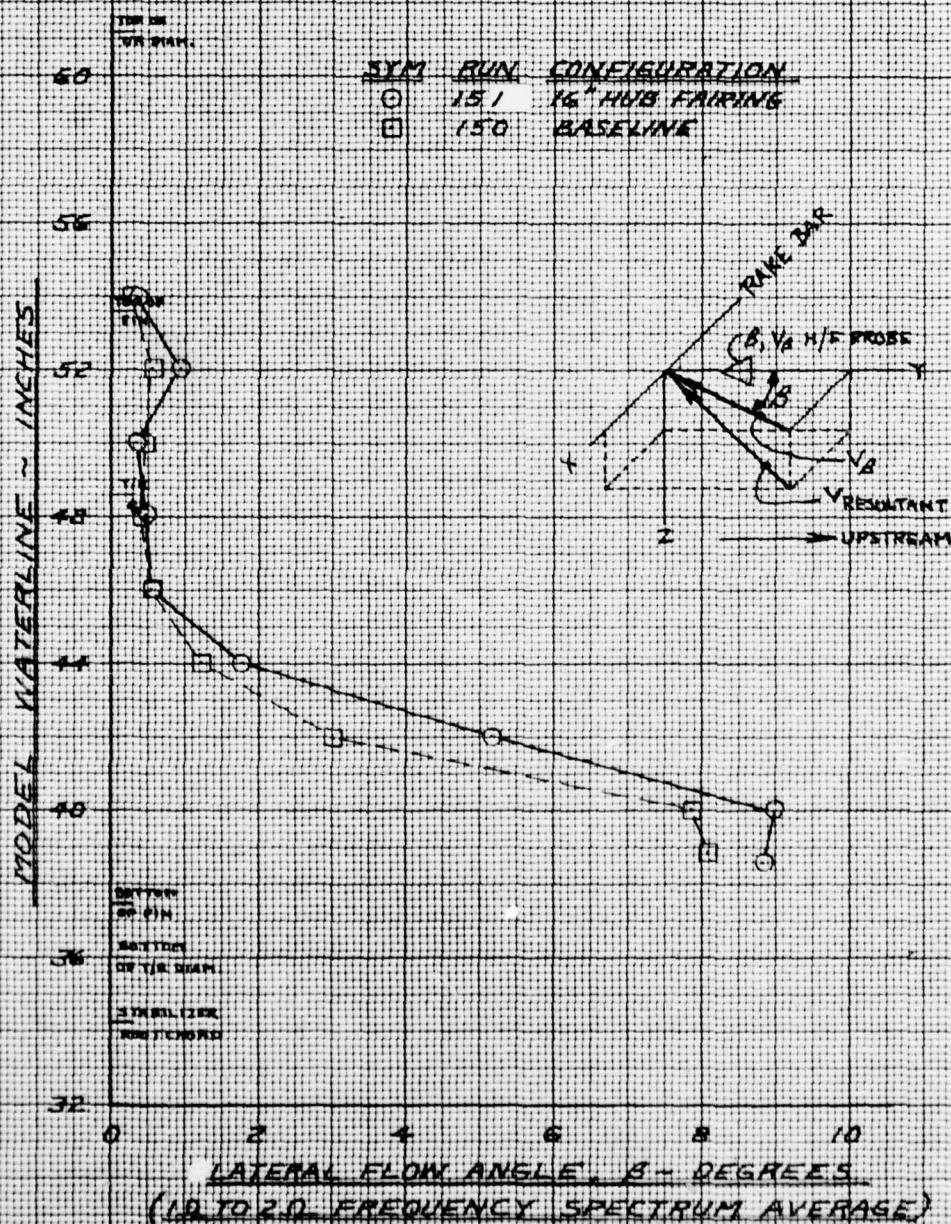
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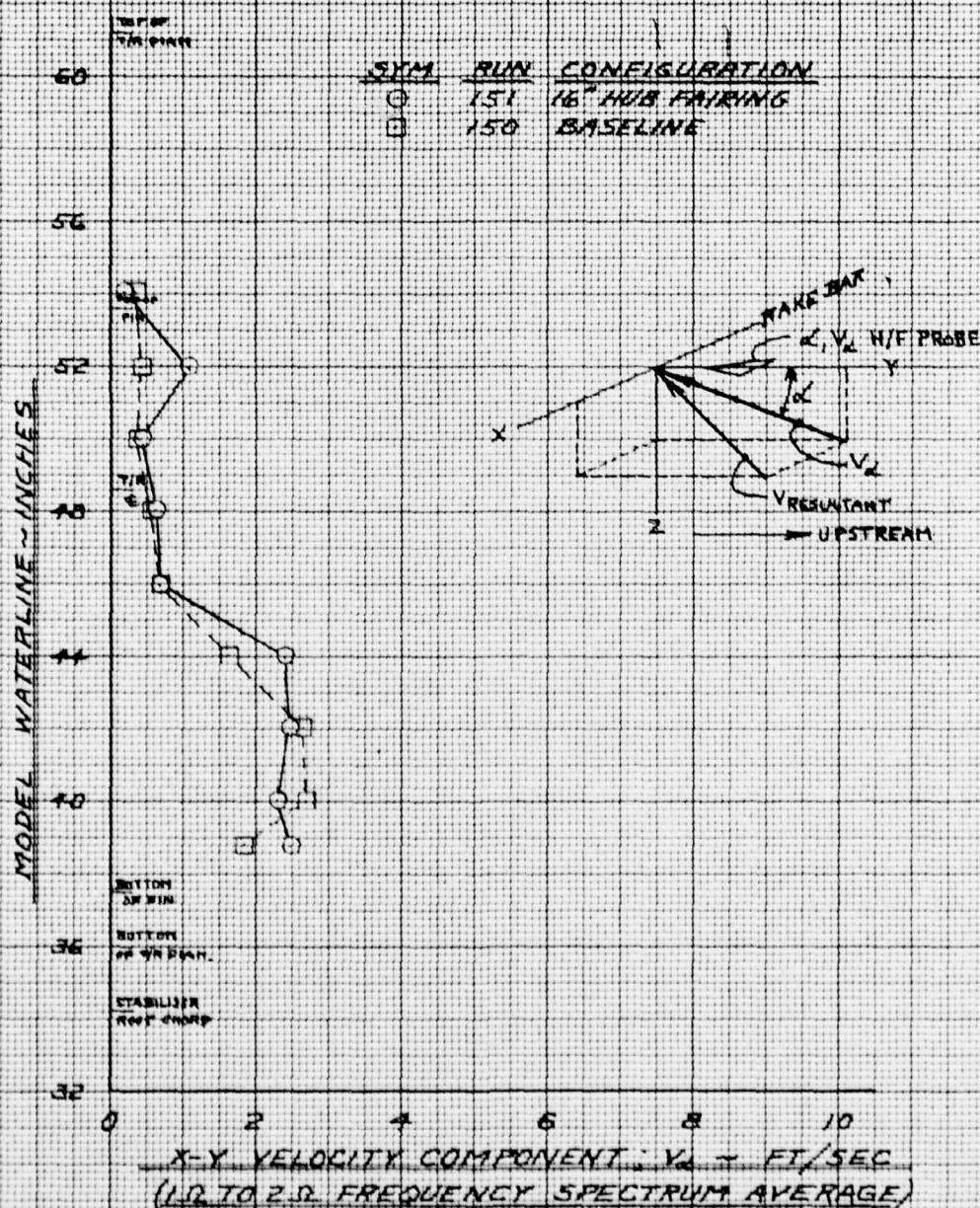
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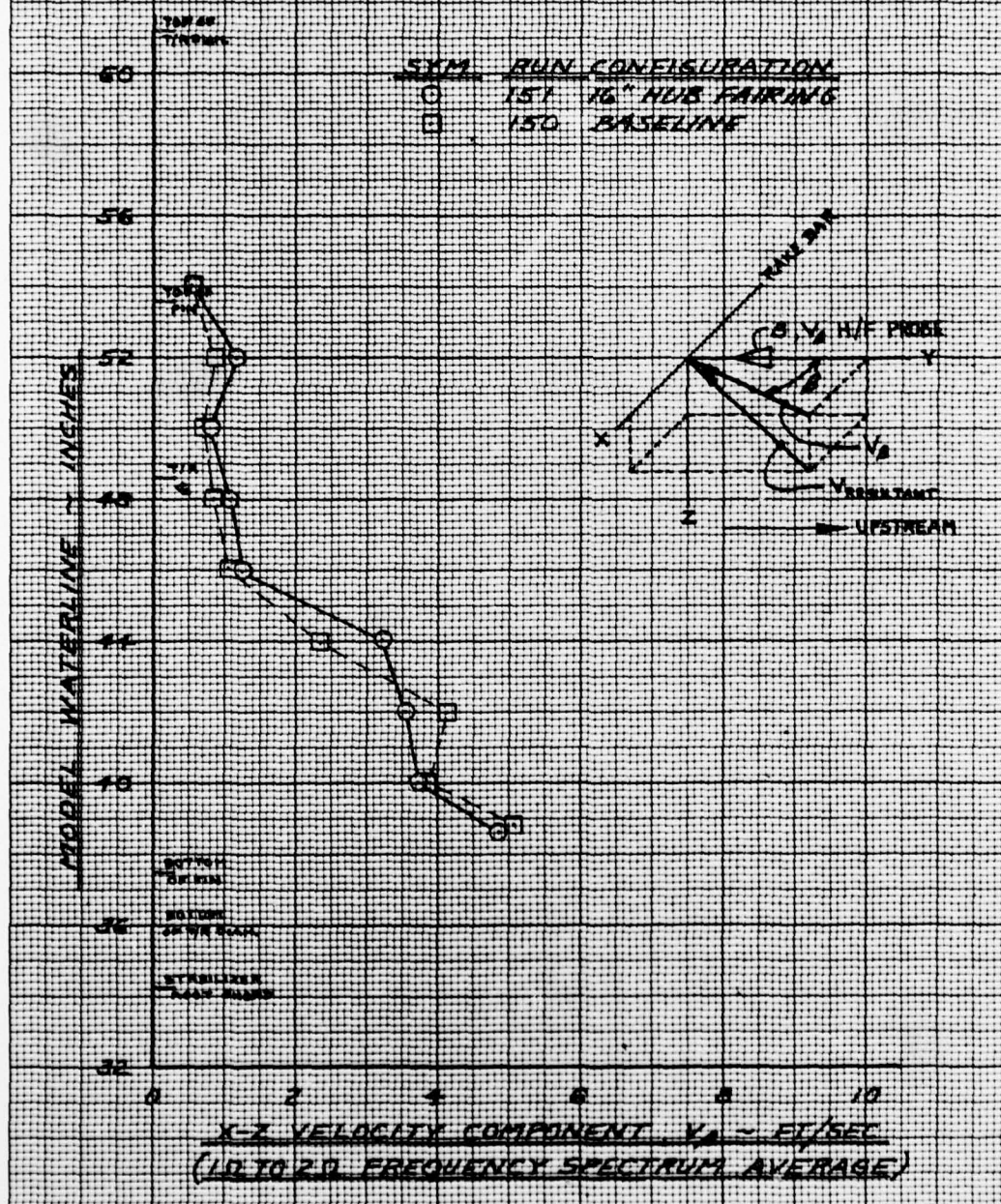
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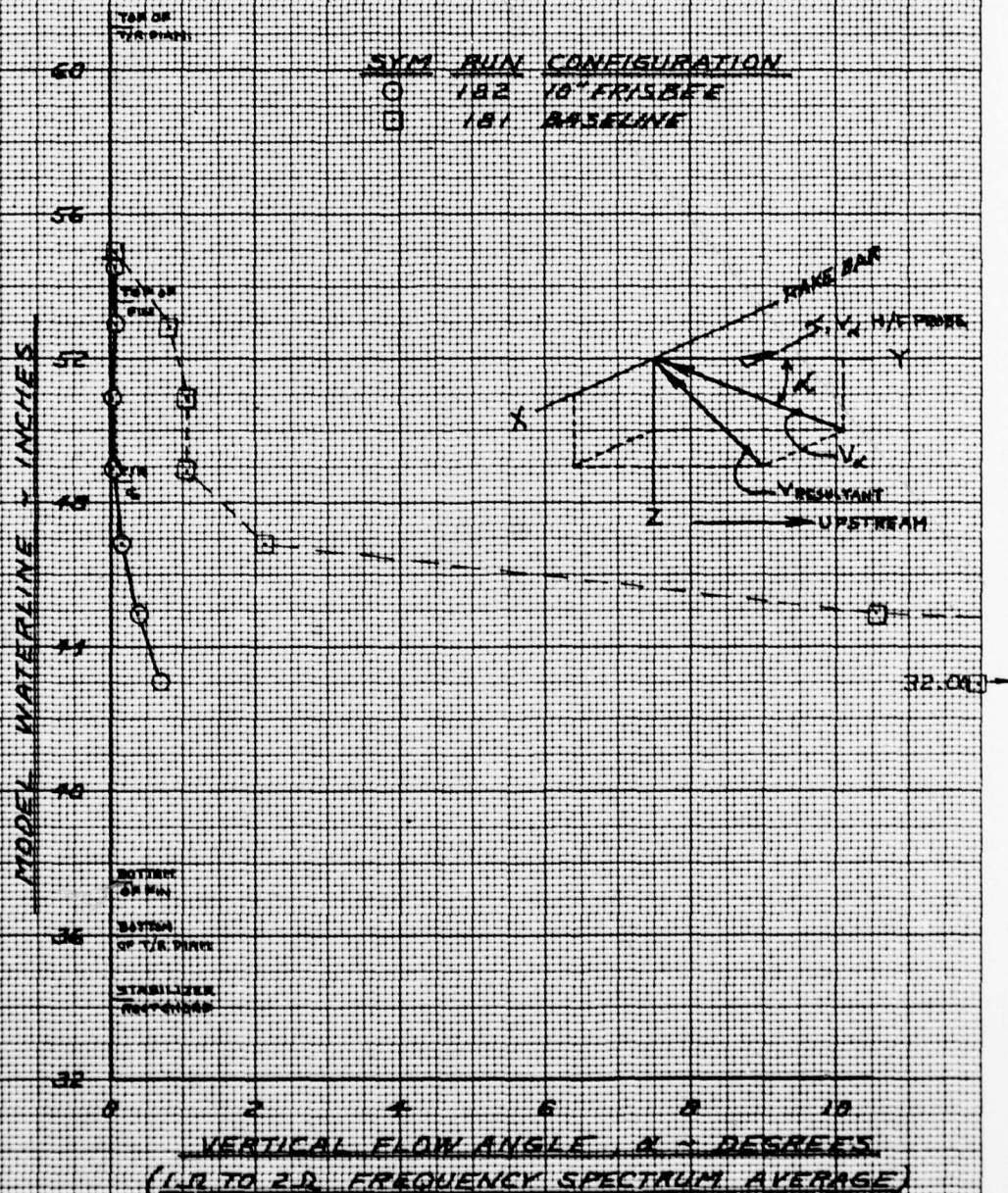
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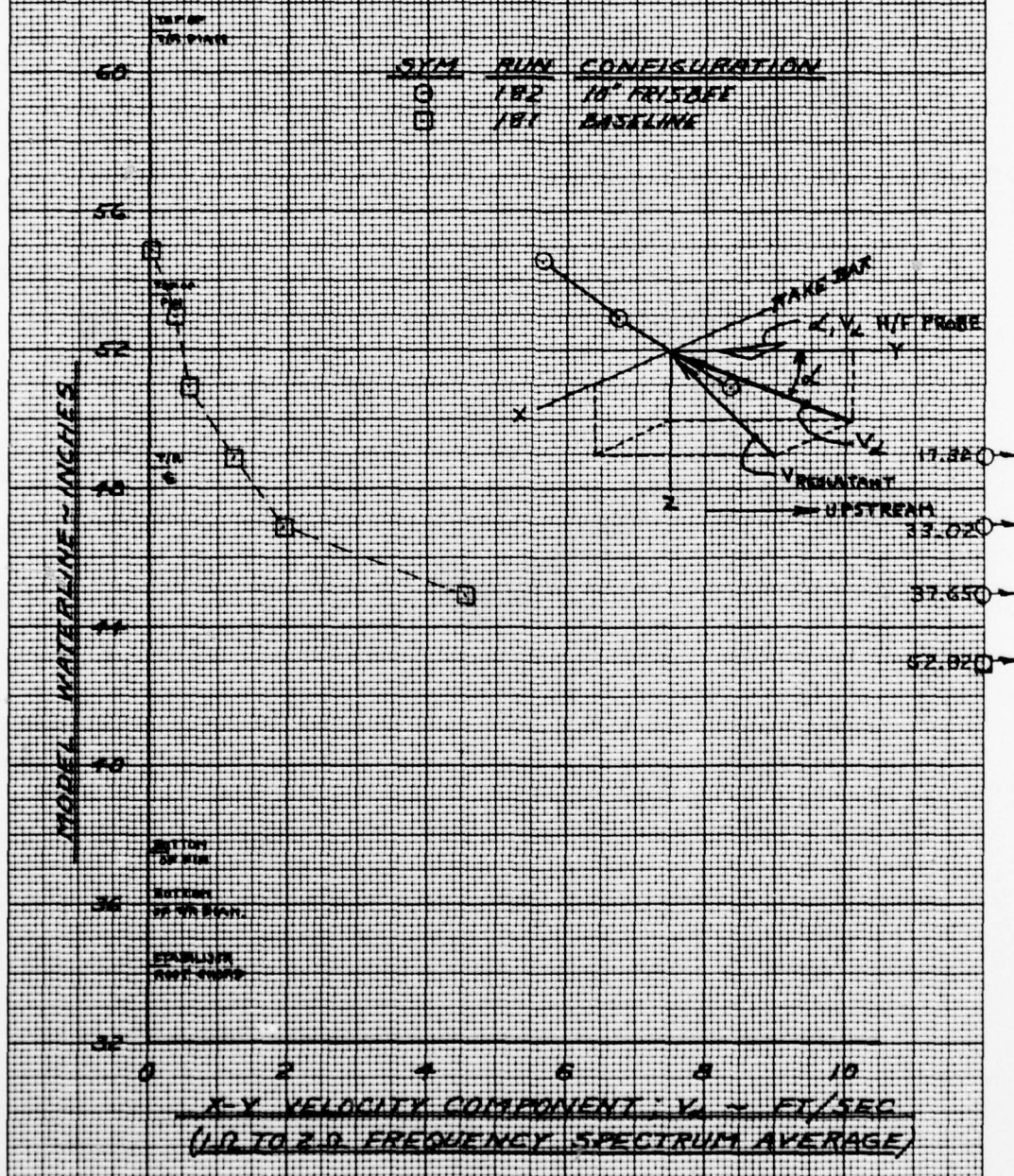


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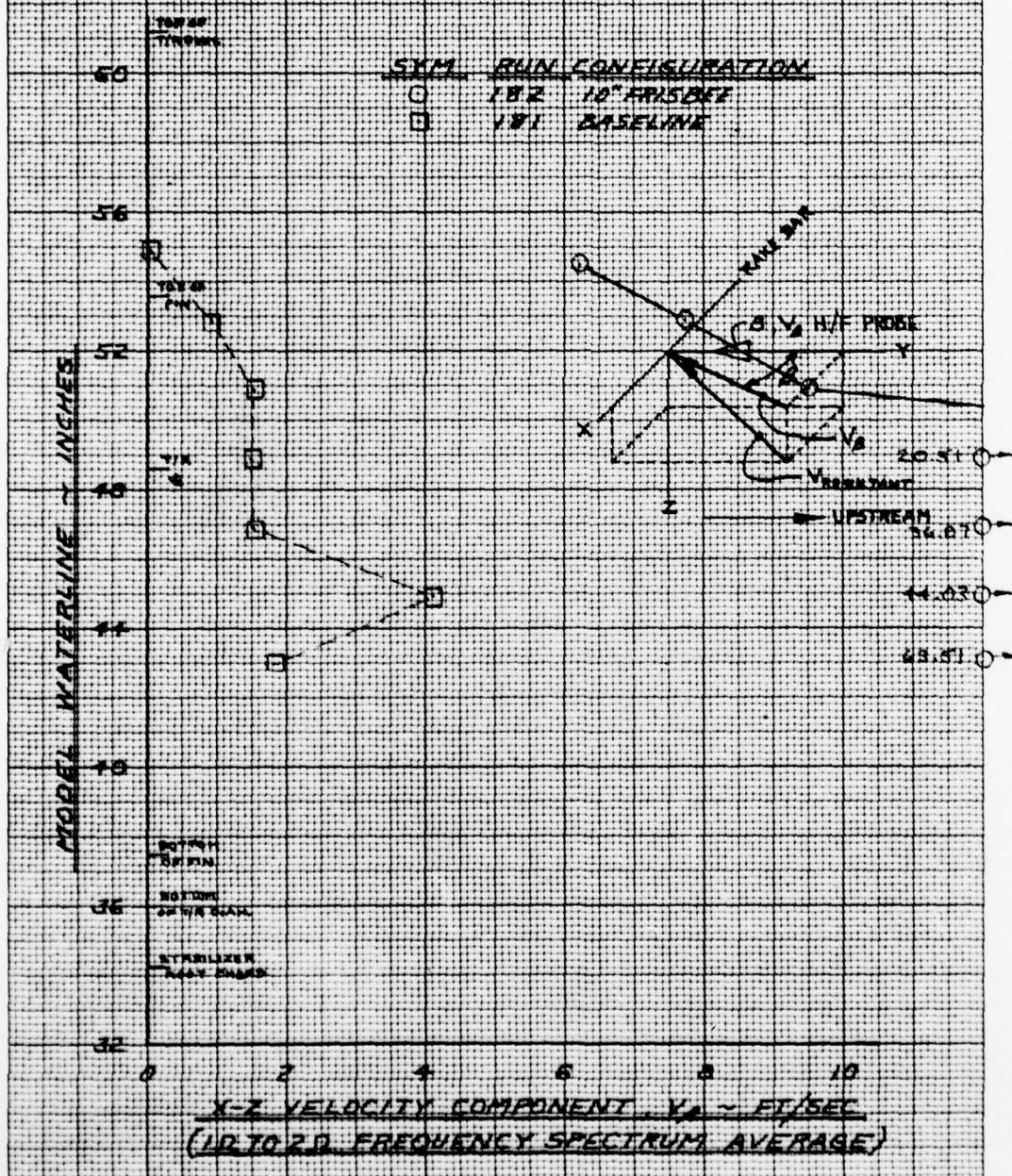
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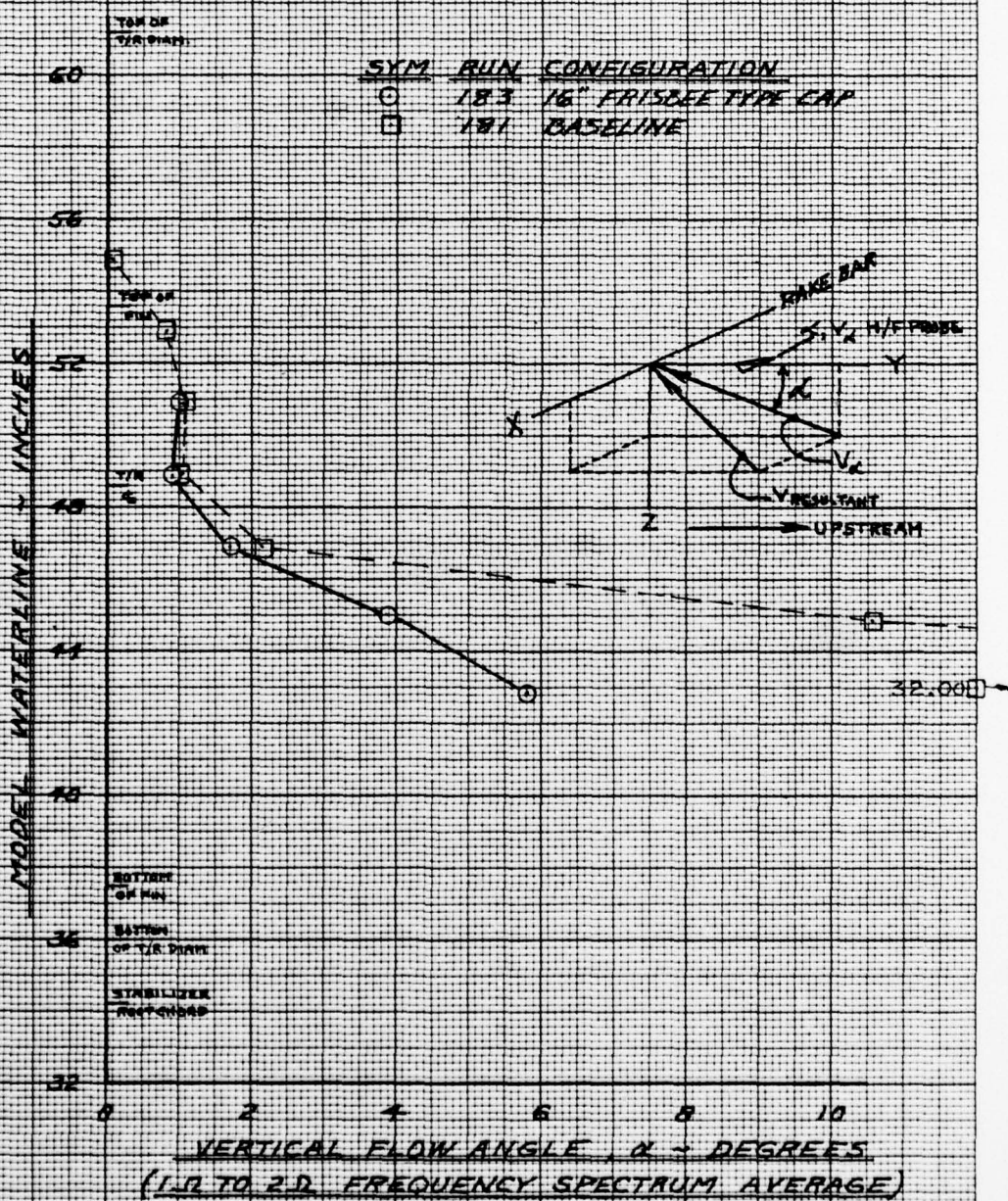
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